INTEROCEANIC CANAL STUDIES 1970

Atlantic-Pacific Interoceanic Canal Study Commission

ATLANTIC-PACIFIC INTEROCEANIC CANAL STUDY COMMISSION
726 JACKSON PLACE, N.W.
WASHINGTON, D.C. 20506

December 1, 1970

APR 15 1971

The President
The White House
Washington, D. C.

Dear Mr. President:

We have the honor to submit herewith the final report of the Atlantic-Pacific Interoceanic Canal Study Commission as required by Public Law 88-609, 88th Congress, as amended.

One provision of the law required us to determine the practicability of nuclear canal excavation. Unfortunately, neither the technical feasibility nor the international acceptability of such an application of nuclear excavation technology has been established at this date. It is not possible to foresee the future progress of the technology or to determine when international agreements can be effectuated that would permit its use in the construction of an interoceanic canal. Hence, although we are confident that someday nuclear explosions will be used in a wide variety of massive earth-moving projects, no current decision on United States canal policy should be made in the expectation that nuclear excavation technology will be available for canal construction.

The construction of a sea-level canal by conventional means is physically feasible. The most suitable site for such a canal is on Route 10 in the Republic of Panama. Its construction cost would be approximately $2.88 billion at 1970 price levels. Amortization of this cost from toll revenues may or may not be possible, depending on the growth in traffic, the time when the canal becomes operative, the interest rate on the indebtedness, and payments to the host country. We believe that the potential national defense and foreign policy benefits to the United States justify acceptance of a substantial financial risk.

As a first step, we urge that the United States negotiate with Panama a treaty that provides for a unified canal system, comprising both the existing canal and a sea-level canal on Route 10, to be operated and defended under the effective control of the United States with participation by Panama.

If suitable treaty arrangements are negotiated and ratified and if the requisite funds can then be made available, we recommend that construction

of a sea-level canal be initiated on Route 10 no later than 15 years in advance of the probable date when traffic through the present canal will reach its transit capacity. Current trends indicate that this will be near the end of this century; the specific year can be projected with increasing confidence as it draws nearer.

We recognize, however, that the President of the United States and the Congress will continue to face many serious funding problems and must establish the relative priorities of the requirements for defense, welfare, pollution, civil rights, crime, and other problems in social undertakings then existing.

We specifically recommend that, when the rights and obligations of the United States under new treaties with Panama are determined, the President reevaluate the need and desirability for additional canal capacity in the light of canal traffic and other developments subsequent to 1970, and take such further steps in planning the construction of a sea-level canal on Route 10 as are then deemed appropriate.

Respectfully,

Robert G. Storey

Milton S. Eisenhower

Kenneth E. Fields

Raymond A. Hill

Robert B. Anderson, Chairman

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Raymond A.
Hill

Robert G.
Storey
Vice Chm.

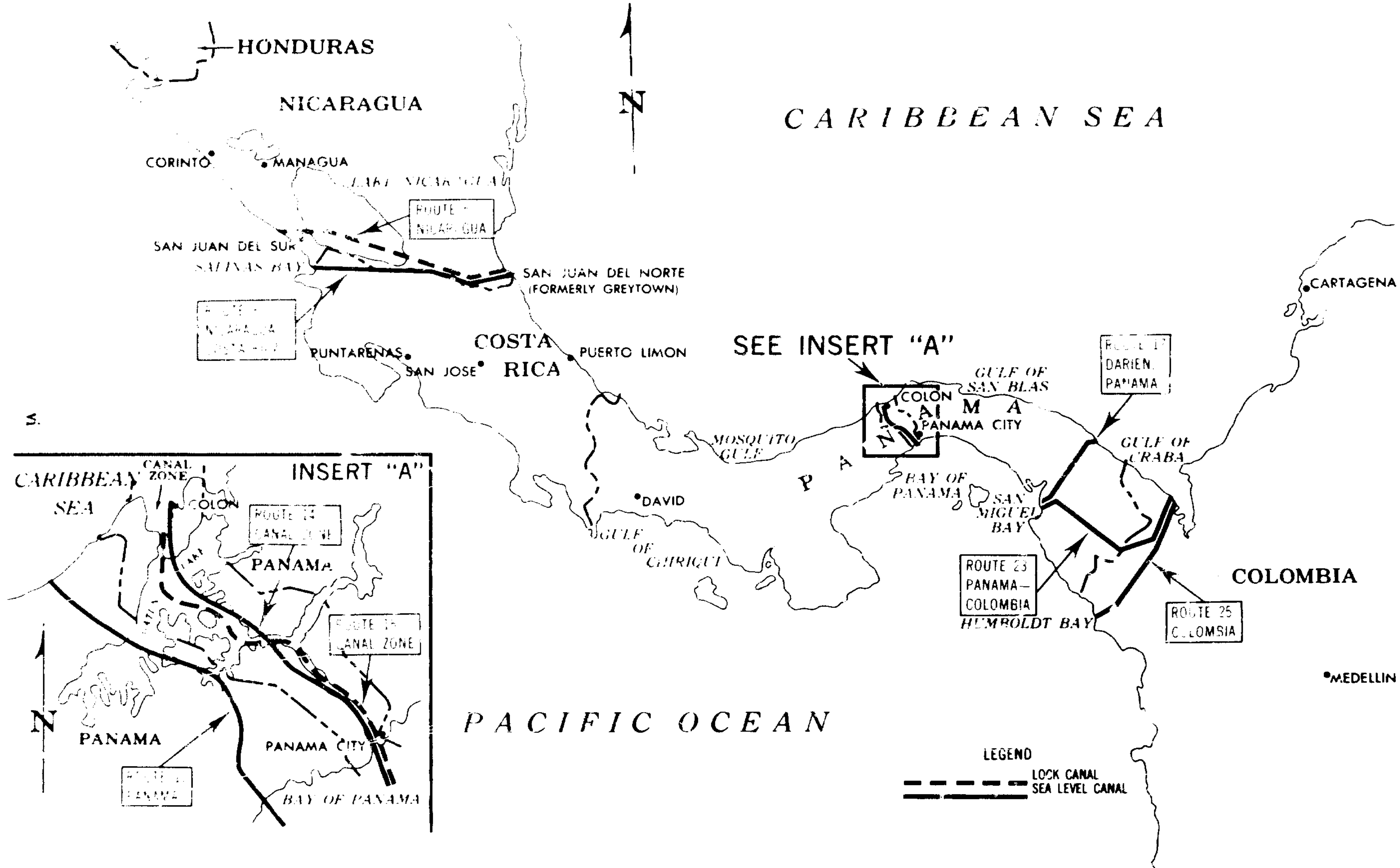
Robert B.
Anderson
Chairman

Milton S.
Eisenhower

Kenneth E.
Fields

COMMISSION EXECUTIVES

Executive Director	–	John P. Sheffey
Engineering Agents	–	Brigadier General Harry G. Woodbury, U.S. Army (June 24, 1965 to June 18, 1967)
	–	Brigadier General Charles C. Noble, U.S. Army (June 19, 1967 to January 26, 1969)
	–	Brigadier General Richard H. Groves, U.S. Army (January 27, 1969 to the present)
Secretary	–	Edward W. McGregor



CANAL ROUTES

FIGURE 1

REPORT OF THE ATLANTIC-PACIFIC INTEROCEANIC CANAL STUDY COMMISSION

CHAPTER I

INTRODUCTION

The Atlantic-Pacific Interoceanic Canal Study Commission was required by Public Law 88-609 of the 88th Congress, September 22, 1964, (Enclosure 1) ". . . to make a full and complete investigation and study, including necessary on-site surveys, and considering national defense, foreign relations, intercoastal shipping, interoceanic shipping, and such other matters as they may determine to be important, for the purpose of determining the feasibility of, and the most suitable site for, the construction of a sea-level canal connecting the Atlantic and Pacific Oceans; the best means of constructing such a canal, whether by conventional or nuclear excavation, and the estimated cost thereof." The Commission interpreted its mission also to require, for the purpose of comparison, an evaluation of the merits of improving and augmenting the existing Panama Canal to accommodate forecast traffic.

On December 18, 1964, President Lyndon B. Johnson announced the willingness of the United States to negotiate with the Republic of Panama a new treaty to replace the Treaty of 1903. At the same time he stated that the United States would request rights to conduct on-site investigations of potential sea-level canal routes not only in Panama but also in Colombia, Nicaragua, and Costa Rica. The President said:

***

> "For fifty years the Panama Canal has carried ships of all nations in peaceful trade between the two great oceans – on terms of entire equality and at no profit to this country. The Canal has also served the cause of peace and freedom in two world wars. It has brought great economic contributions to Panama. For the rest of its life the Canal will continue to serve trade, and peace, and the people of Panama.
>
> But that life is now limited. The Canal is growing old, and so are the Treaties for its management, which go back to 1903.
>
> ***
>
> So I think it is time to plan in earnest for a sea-level canal. Such a canal will be more modern, more economical, and will be far easier to defend. It will be free of complex, costly, vulnerable locks and sea-ways. It will serve the future as the Panama Canal we know has served the past and the present."

When President Richard M. Nixon took office in January 1969, he retained the originally appointed Commission and requested it to continue the investigation to its completion.

The Commission has been guided in its investigation by numerous earlier canal studies. The most recent of these were:

- The 1947 study conducted by the Governor of the Panama Canal.
- The 1960 study by the House Committee on Merchant Marine and Fisheries.

- The 1960 and 1964 studies by the Panama Canal Company.

These earlier studies evaluated all potential canal routes across Central America and thus enabled the Commission to concentrate its efforts on the most promising ones.

Canal Treaties

The Commission has had no role in the treaty negotiations with Panama conducted by its Chairman, Robert B. Anderson, in his separate capacity as Special Representative of the United States for United States-Panama Relations.

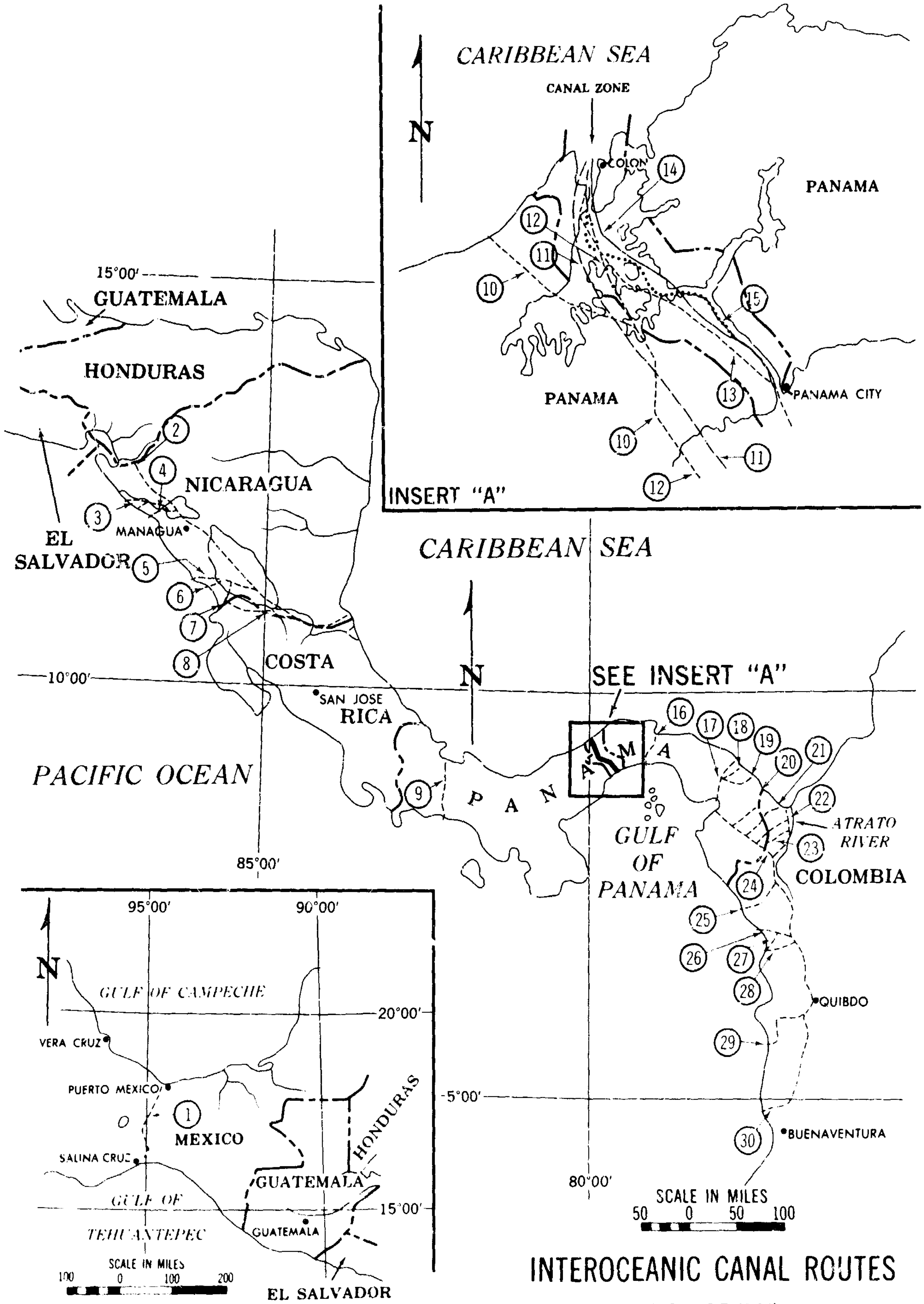
The Commission assumed at the outset of its studies that construction of any sea-level canal would require new treaty arrangements between the United States and the host country. Existing treaties with Panama and Nicaragua do not provide authority for construction of a sea-level canal in either country, and no existing treaties provide the United States canal rights in Costa Rica or Colombia. In addition, no treaty in force provides for multinational participation in canal finance or management.

During the first 2 years of the Commission's investigation, treaty negotiations with the Republic of Panama were in progress. In June 1967, the negotiators reached agreement on drafts of three new treaties to replace the Treaty of 1903 – one for the continued operation of the existing canal, another for United States rights to build and operate a sea-level canal in Panama, and a third for canal defense. However, neither Government initiated ratification procedures thereafter, and in 1970 the Government of Panama announced its rejection of the draft treaties. In both countries new administrations have replaced those in office when the draft treaties were developed. The drafts have no legal status; they represent only the United States and Panamanian negotiators' judgments in 1967 of what might have been acceptable to their respective Governments at that time. However, the Commission has been mindful of relevant provisions of the draft treaties in its consideration of possible future treaty arrangements that would bear upon the feasibility of a sea-level canal in Panama.

Selection of Alternatives for Evaluation

In October 1962, the Secretary of the Army formed a Technical Steering Committee to review prior studies and to develop a new canal study plan for presentation to the Congress. The sea-level canal routes recommended in this plan were selected from those found most promising in the 1947 study conducted by the Governor of the Panama Canal which identified 30 potential routes and assigned them numbers that have been used in all subsequent studies (Figure 2). Those recommended for investigation in the plan proposed to the Congress by the Secretary of the Army, with consideration of the potential of nuclear excavation, were

- Route 8 in Nicaragua and Costa Rica for a sea-level canal constructed primarily by nuclear excavation.
- Route 14 in the Canal Zone for conversion of the present lock canal to sea level by conventional construction methods.
- Route 17 in Panama for a sea-level canal constructed primarily by nuclear excavation.
- Route 25 in Colombia for a sea-level canal constructed by a combination of nuclear and conventional excavation methods.



INTEROCEANIC CANAL ROUTES

FIGURE 2 (1947 STUDY)

The Congress authorized the new canal study on September 22, 1964. The original legislation contemplated investigation of these four routes and authorized funds for field surveys only of Routes 17 and 25. Data available from previous studies were believed to be adequate for evaluations of Routes 8 and 14.

When the Commission was appointed in April 1965, it requested the Secretary of State, the Secretary of the Army, and the Chairman of the Atomic Energy Commission to serve as its Advisory Council. Interdepartmental study groups were then organized to conduct studies under the Commission's direction as follows:

- Study of Foreign Policy Considerations
- Study of National Defense Aspects.
- Study of Canal Finance.
- Study of Interoceanic and Intercoastal Shipping.
- Study of Engineering Feasibility (directed by the Chief of Engineers, United States Army, in coordination with the Atomic Energy Commission and the Panama Canal Company).
- Study of Public Information Requirements
  (subsequently combined with the Study of Foreign Policy Considerations).

The study groups included representation from all government agencies with significant interests in an Isthmian canal. They also used private contract agencies for supporting technical studies.

The Commission employed a panel of eminent private consultants which it designated as its Technical Associates for Geology, Slope Stability, and Foundations. These specialists provided technical advice directly to the Commission on engineering matters and were also made available to the Commission's Engineering Agent to advise and assist him in the conduct of the Study of Engineering Feasibility.

At the outset of its studies, the Commission approved investigation of the four routes recommended to the Congress by the Secretary of the Army. A few months later the Commission directed its Engineering Agent to update earlier cost estimates for improvements to the existing lock canal and for construction of a new lock canal in Nicaragua; these estimates were needed to permit comparisons with the alternative sea-level canals in terms of capacities and construction, operation, and maintenance costs.

As the engineering study of Route 14 progressed it became apparent that an alternate route nearby, one that did not interfere with the existing canal, might be preferable. Consequently, in June 1966 Route 10 was added to the routes under consideration. The Congress subsequently provided additional funds for a limited field investigation of this route.

As the geological drilling program on Route 17 progressed, it became apparent that there was little possibility that nuclear means could be used for excavation of approximately one-third of the route. Hence, the plan for evaluation of this route was revised late in 1967 to provide for excavation of approximately 20 miles of its length by conventional methods.

In 1969 the Government of Colombia informally proposed a joint U.S.-Colombian-Panamanian investigation of Route 23. The Commission advised Colombian representatives

that the route did not appear to be competitive with routes already under consideration but agreed to include in its final report an analysis of it based upon available data.

Table 1 lists all the routes given specific consideration in the course of the Commission's investigation. A detailed discussion of the selection of these routes is contained in Annex V, Study of Engineering Feasibility.

TABLE 1

CANAL ROUTES SELECTED FOR COMMISSION INVESTIGATION

Route No.	Route Name	Country	Type of Canal/ Excavation Method	Basis of Evaluation
5	San Juan del Norte-Brito	Nicaragua and Costa Rica	Lock/Conventional	Available data
8	San Juan del Norte-Salinas Bay	Nicaragua and Costa Rica	Sea-Level/Conventional or Nuclear	Available data
10	Chorrera-Lagarto	Panama	Sea-Level/Conventional	Available data augmented by geological investigations
14-Combined	Panama Canal Sea-Level Conversion	Canal Zone	Sea-Level/Conventional	Available data augmented by geological investigations
14-Separate	Panama Canal Sea-Level Conversion	Canal Zone	Sea-Level/Conventional	Available data augmented by geological investigations
15	Panama Canal	Canal Zone	Lock/Conventional	Available data
17	Sasardi-Morti	Panama	Sea-Level/Conventional and Nuclear Combination	Comprehensive on-site survey
23	Atrato-Tuira	Colombia and Panama	Sea-Level/Conventional or partially Nuclear	Available data augmented by data from surveys on Routes 17 and 25.
25	Atrato-Truando	Colombia	Sea-Level/Conventional and Nuclear Combination	Comprehensive on-site survey

CHAPTER II

ISTHMIAN CANAL INTERESTS OF THE UNITED STATES AND OTHER NATIONS

The United States entered the Isthmus of Panama in 1903 to build a canal to serve world commerce and contribute significantly to the national security of the United States. In the years since its opening in August 1914, the Panama Canal has played a major role in the defense of the United States and its value as an international public utility serving ocean trade has increased dramatically.

Although less than 5 per cent of canal tonnages in recent years has been United States intercoastal trade and although most merchant ships now using the Panama Canal are not of United States registry, approximately 70 per cent of all canal cargoes either originate in or are destined for the United States. More than 40 per cent of the ocean trade of the Pacific Coast countries of South America passes through the canal. Japan, Canada, Venezuela, and Chile are major users, and almost every country in the world has some trade on the canal routes.

The policy of the United States has been to operate the Panama Canal on a non-profit basis for the benefit of all users. No specific effort has been made to amortize the United States investment in the canal. With the exception of a few small repayments to the Treasury, revenues in excess of operating and interest costs have been devoted to capital improvements.

The initial investment of $387 million was too great to be amortized by reasonable tolls during the canal's early years. Tolls were set at 90 cents per measurement ton (100 cubic feet of cargo space) for laden vessels, 72 cents per measurement ton for vessels in ballast, and 50 cents per displacement ton for warships and other non-cargo vessels. From 1914 to 1951 the canal was maintained and operated by annual appropriations from the United States Treasury, while annual receipts were returned to the Treasury. Not until after World War II did revenues approach operating costs. In 1951 the Panama Canal Company was organized as a United States Government corporation under legislation which permitted continuation of the previously established toll levels but authorized increases when needed to meet operating costs, interest on the unamortized investment, and a proportionate share of the cost of the Canal Zone Government. In arriving at the interest-bearing debt* of the Company the Congress set it at a minimum to lessen the interest burden on toll revenues. All capital costs that reasonably could be attributed to defense or other activities not required for ship transits were written off. No provision was made for payment of the

*The Panama Canal Company's interest-bearing debt was established in 1951 at $373 million. (See Public Law 841, 81st Congress, September 26, 1950, 64 Stat. 1041; Hearings before the Subcommittee on the Panama Canal of the Committee on Merchant Marine and Fisheries, House of Representatives, on H.R. 8677, 81st Congress, June 26-28, 1950; Hearing before the Committee on Armed Services, United States Senate, on H.R. 8677, 81st Congress, September 7, 1950.) As of June 30, 1970 it had been reduced by write-offs and repayments to $317 million. As of this same date the total unrecovered United States investment in the canal, including unpaid interest accrued since 1903, was estimated by the Company to be $700 million, excluding defense costs.

Culebra Cut, the deepest excavation of the Panama Canal, June 1913

FIGURE 3

interest obligation which had accumulated prior to the creation of the Company, and the formula prescribed for calculating the interest rate on the debt was designed to keep current interest payments low. The legislation creating the Company did not permit it to increase tolls for the purpose of amortizing its debts.

Since 1951 the Congress has continued to confirm its intent to maintain low tolls. When the canal annuity to Panama was increased $1.5 million by treaty agreement in 1955 the Congress stipulated that the increase be paid through an appropriation to the Department of State. This arrangement continues today; only $430,000 of the $1,930,000 annuity is included as a cost of canal operation. Hence, meeting the legally established payment objectives of the Panama Canal Company has not required an increase in the toll rates set in 1914.

Interests of the United States

The objectives of the United States in an Isthmian canal are:

- That it always be available to the world's vessels on an equal basis and at reasonable tolls,

- That it serve its users efficiently, and
- That the United States have unimpaired rights to defend the canal from any threat and to keep it open in any circumstances, peace or war.

National Security

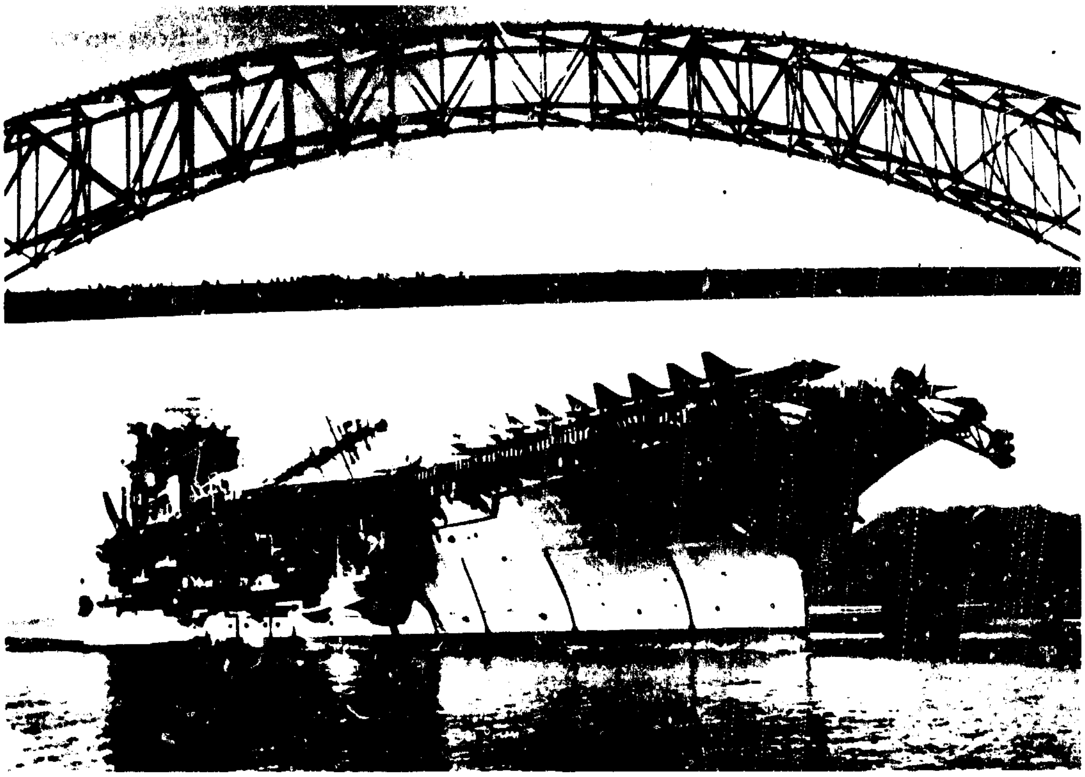
The present Panama Canal plays an important role in the United States national defense; this is analyzed in Annex II, Study of National Defense Aspects. In World War II (1941-1945), United States Government vessels made 20,276 transits, and 24 million tons of military supplies passed through the canal. During the Korean War (1951-1954), United States Government vessels made 3,331 transits, and 12 million tons of supplies went through. It played an important role in the deployment of naval vessels during the Cuban crisis in 1962, and currently a large portion of the military vessels and military supplies bound for Vietnam passes through the canal.

Closure of the Panama Canal in wartime would have the same effect on United States military capabilities as the loss of a large number of ships. Many additional ships would be needed to support military operations effectively via alternate routes, particularly operations in the Pacific area. The canal's major military importance is in the logistic support of combat forces overseas; internal United States transportation systems and port complexes could be severely burdened in wartime if cargo movements had to be diverted from canal routes. In an emergency, combat vessels can be deployed between the oceans by other routes, but the capacities of available shipping, ports, and domestic transportation cannot be quickly augmented to compensate for canal closure.

Panama has neither sufficient military strength to defend the Panama Canal nor the capability of developing such strength. The presence of United States forces is essential for the security of the canal. This limited role of the United States forces in the Canal Zone has created no great difficulties with Panama. The defense of the canal, however, is an integral part of the defense of the Americas; Panamanian Governments in the past have expressed objections to the planning and execution of hemisphere defense activities from Zone bases.

The existing Panama Canal is vulnerable to many forms of attack, even though extensive protective measures have been taken to strengthen the dams holding its water supply, to double-gate the canal locks, and to guard its power sources. Drainage of Gatun Lake is the greatest danger. A guerrilla raid on the locks or dams or the demolition of a shipload of explosives in the locks could result in the loss of stored water that could take as long as 2 years to replace. Shorter term interruptions could readily be created by sabotage of power supplies and lock machinery, by scuttling ships in the locks or channel, or by harrassment by fire on ships in transit. Considering its vulnerabilities, little comfort can be drawn from the fact that no interruption of canal operations by hostile forces has occurred, for no military or guerrilla attack on the canal has yet been attempted. The United States must have a secure Isthmian canal, and its defense can best be accomplished in conjunction with defense of the surrounding area at great distances from the canal itself.

Although it could not be put in operation for many years to come, a sea-level canal across the American Isthmus would increase the security of the United States and other countries in the Western Hemisphere. It would be much less vulnerable to interruptions and hence easier to defend. The current weaknesses of locks and power and water supply would



The United States Navy Aircraft Carrier CONSTELLATION passing under the Thatcher Ferry Bridge over the Panama Canal. This carrier, with a 250-foot wide flight deck, is too wide to pass through the 110-foot wide locks of the present canal.

FIGURE 4

not exist. Blockages by scuttled ships or bomb-induced slides could be removed relatively quickly and the possibility is remote that it could be closed for long periods by hostile action.

Canal Treaties

The principal treaties bearing upon United States canal rights and obligations on the American Isthmus are:

- The Gadsden Treaty of 1853 with Mexico which guaranteed to the United States freedom of transit across the Isthmus of Tehuantepec should any means of transit be constructed there.
- The Hay-Pauncefote Treaty of 1901 with Great Britain which cancelled an earlier agreement with Britain that the United States would not fortify any canal across the Isthmus and provided that the United States could alone build, operate, and protect the Isthmian canal, provided it was neutral and open to the world's vessels on an equal basis.
- The Hay-Herran Treaty of 1903 with Colombia (never ratified) which would have given the United States the right to construct a canal in the Province of Panama. Failure of the Colombian Government to ratify this treaty led to the creation of

the Republic of Panama, and signature of the Hay-Bunau Varilla Treaty of 1903 with Panama.

- The Hay-Bunau Varilla Treaty of 1903 with Panama which gave the United States in perpetuity the exclusive right to build and operate a canal across Panamanian territory and all the rights as if sovereign in the Canal Zone.
- The Bryan-Chamorro Treaty of 1914 with Nicaragua (now in process of being abrogated) which gave the United States the right in perpetuity to construct an interoceanic canal across Nicaraguan territory.
- The Thompson-Urrutia Treaty of 1914 (ratified in 1922) with Colombia which gave to Colombia the right of toll-free passage of the Panama Canal for her government-owned vessels.
- The 1936 and 1955 treaties with Panama which relinquished some United States rights acquired in 1903 and provided additional benefits for Panama but did not fundamentally change the 1903 Treaty relationship.

Treaty Negotiations, 1964-1967

The draft three-treaty package developed by United States and Panamanian negotiators between 1964 and 1967, never signed or ratified, and rejected by the Government of Panama in 1970, contained these major provisions:

- The first of the proposed treaties, that for the continued operation of the present canal, would have abrogated the Treaty of 1903 and provided for: (a) recognition of Panamanian sovereignty and the sharing of jurisdiction in the canal area, (b) operation of the canal by a joint authority consisting of five United States citizens and four Panamanian citizens, (c) royalty payments to Panama rising from 17 cents to 22 cents per long ton of cargo through the canal, and (d) exclusive possession of the canal by Panama in 1999 if no new canal were constructed or shortly after the opening date of a sea-level canal, but no later than 2009, if one were built.
- The second, for a sea-level canal, would have granted the United States an option for 20 years after ratification to start constructing a sea-level canal in Panama, 15 more years for its construction, and United States majority membership in the controlling authority for 60 years after the opening date or until 2067, whichever was earlier. It would have required additional agreements on the location, method of construction, and financial arrangements for a sea-level canal, these matters to be negotiated when the United States decided to execute its option.
- The third, for the United States military bases in Panama, would have provided for their continued use by United States forces 5 years beyond the termination date of the proposed treaty for the continued operation of the existing canal. If the United States constructed a sea-level canal in Panama, the base rights treaty would have been extended for the duration of the treaty for the new canal.

Interests of the Canal-Site Countries

Panama

The Treaty of 1903 with Panama for the construction and operation of the Panama Canal granted to the United States in perpetuity all of the rights as if sovereign in a 10-mile-

wide zone across the Isthmus, to the entire exclusion of the exercise of such rights by the Republic of Panama. The Republic of Panama has sought since 1903 to terminate the sovereignty and perpetuity clauses of the treaty, to increase her participation in the employment and financial benefits deriving from the canal, and to reduce both the substance and the appearance of United States control of Panamanian territory. The treaties of 1936 and 1955 made limited concessions to Panama, but were short of meeting Panamanian aspirations.

Panama has indicated in past treaty negotiations that she considers her fundamental interests in any canal across her territory to be:

- That it be operated and defended with full recognition of the sovereignty of the Government of Panama.
- That Panama obtain the maximum possible revenues from the canal in direct payments and through Panamanian employment and sales of goods and services in the canal enterprise.
- That Panama eventually become sole owner and operator of the canal.

The differing canal objectives of the United States and Panama have continued to impair tranquil relations. Destructive riots took place along the Canal Zone border in 1959 and in 1964. New treaty negotiations, begun in 1964 and as yet unfinished, have as their goal the reconciliation of the interests of both countries in a lasting agreement.

There are many constraints upon the United States in meeting Panamanian aspirations, but the United States has demonstrated, in the treaties of 1936 and 1955 and in negotiating the 1967 draft treaties, a sincere desire to go as far as it can without jeopardy to its own canal objectives.

The existing lock canal requires a large staff of skilled operating personnel, and its defense requires substantial military forces. The Canal Zone provides a United States standard of living for the 4,000 United States citizen employees of the canal, mostly executives and skilled craftsmen. The Zone military bases provide similar living standards for 13,500 military and civilian personnel. These canal and military personnel are accompanied by approximately 20,500 dependents. This results in some 38,000 United States citizens living in an enclave extending across the middle of the Republic of Panama.

The living conditions provided by the Canal Zone were needed in the past to attract and retain skilled employees, but modern Panama's economy could provide housing and commercial services equivalent to those of the present Canal Zone. Panama's capability of providing skilled personnel is steadily increasing, and the Panama Canal Company has for some years maintained training programs for its Panamanian employees. Consequently, skilled employee positions are increasingly being filled by Panamanian citizens. An employee phase down in a change over to a sea-level canal would hasten the elimination of what is now deemed by Panamanians to be discrimination in favor of United States citizens in canal employment. These prospects offer means for reducing or eliminating several politically sensitive elements in the current situation.

The Panama Canal and its associated United States military bases provide a major portion of the economic lifeblood of Panama. Although Panama's direct annual compensation is slightly less than $2 million, more than $100 million each year is paid to Panamanians for goods and services supplied to the Canal Zone. Panama's economy is growing more rapidly than the economies of other Latin American countries. Canal

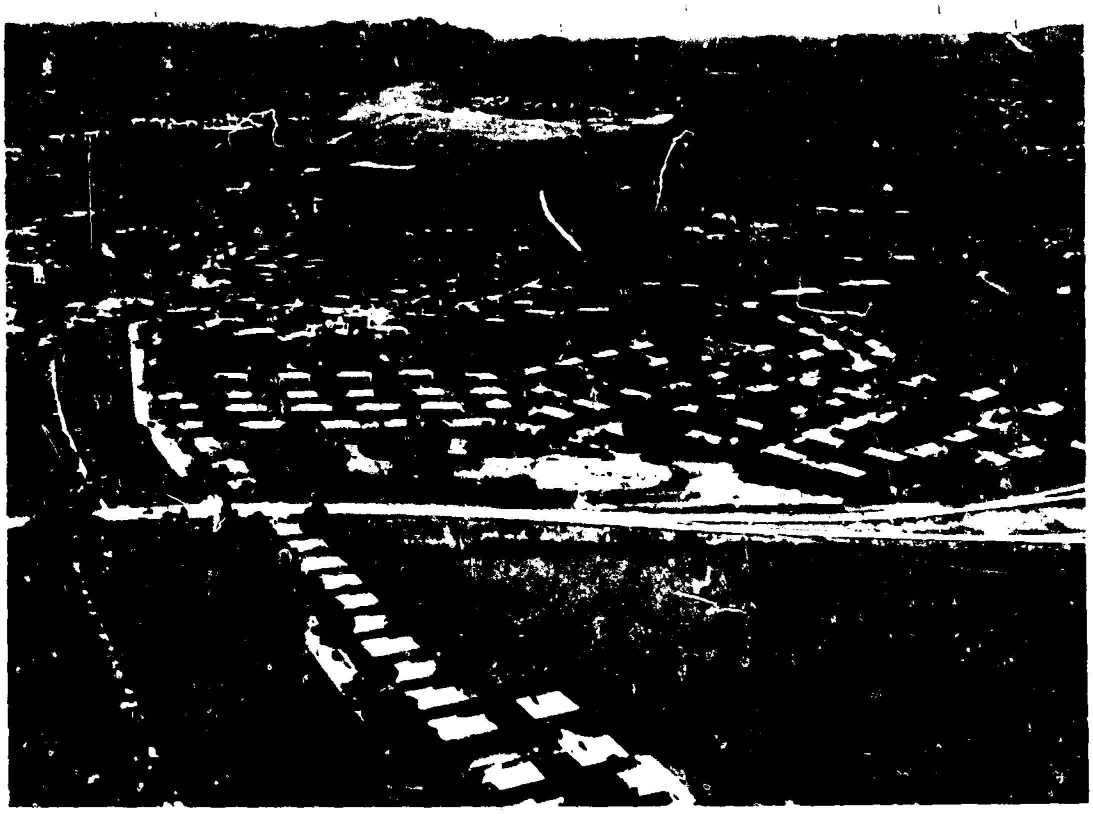
operations and defense are expected to continue to be the basis for about two-thirds of her foreign exchange earnings and one-third of her total economic activity, at least during the remainder of this century.

A United States decision to construct a sea-level canal in another country would be an economic catastrophe for Panama. The potential effects are analyzed in Chapter VII, Analysis of Alternatives.

Colombia

The economy of Colombia is larger and more broadly based than that of Panama. Colombia's population is more than 10 times greater, and her metropolitan centers are far removed from Route 25. A sea-level canal constructed in Colombia would be, at least initially, remote from public view and its economic impact would be favorable, although relatively small.

Formal negotiations for sea-level canal treaty arrangements with Colombia have not taken place. Informal discussions by members of the Commission with her representatives and public statements by her officials indicate that a treaty giving the United States effective control of a canal on Colombian territory might be unobtainable in the foreseeable future, and that United States military forces for canal defense could not be stationed in



The Canal Zone town of Balboa at the Pacific end of the canal

FIGURE 5

Colombia. Colombia's representatives acknowledged that construction of a new canal wholly on Colombian territory could be destructive to the economy of Panama; hence, they indicated that any canal arrangement involving Colombia would have to contribute to regional cooperation and not be a source of friction with her neighbors. The Government of Colombia did express willingness to cooperate with the United States and Panama in investigating the feasibility of multilateral finance, control, and defense of a canal on Route 23 traversing the territories of both Panama and Colombia.

Nicaragua-Costa Rica

United States relations with Nicaragua and Costa Rica have traditionally been friendly. The Bryan-Chamorro Treaty of 1914 established United States rights to build a canal in Nicaragua, subject to further agreement upon detailed terms for its construction and operation. Plans for abrogation of this treaty were initiated early in 1970, but new treaty terms attractive to the United States probably would be attainable for a sea-level canal on Route 8, generally along the border between Nicaragua and Costa Rica.

Interests of Canal Users

As previously indicated, the present Panama Canal plays an important role in the economic life of some dozen nations and is used in lesser degrees by most other nations of the world. Although the United States is the largest user of the Panama Canal, its economic importance is greater to several smaller countries, particularly those of the Pacific Coast of South America. Table 2 compares the exports and imports through the canal for various countries in relation to their total ocean trade as a measure of its importance to each. The United States' 15.8 per cent is exceeded by the proportions of 10 other countries whose economies are vitally linked with the canal.

A recent informal opinion survey of Panama Canal users by United States embassies found general satisfaction with operation of the present canal by the United States. The survey also indicated that the maritime nations of the world assume that the United States will continue to provide an adequate interoceanic passage.

TABLE 2

PANAMA CANAL USERS, FISCAL YEAR 1969[1]

Country	Long Tons of Commercial Cargo Origin	Destination	Per Cent of Country's Total Oceanborne Trade
United States	44,010,410	27,618,123	15.8
(U.S. Intercoastal)	(3,851,326)	(3,851,326)	
Japan	7,396,528	33,558,400	11.7
Canada	7,280,101	2,335,207	7.5
Venezuela	8,528,294	704,973	4.7
Chile	3,325,839	4,063,013	39.6
Peru	4,678,162	1,768,126	39.0
United Kingdom	979,589	3,362,642	2.0
Netherlands West Indies	3,720,671	113,646	4.5
Netherlands	470,062	2,737,548	1.7
Australia	1,668,788	1,367,957	4.1
West Germany	790,825	2,085,378	2.6
Ecuador	969,258	1,215,417	72.4
Philippine Islands	1,534,594	545,703	8.3
New Zealand	1,309,822	702,091	17.6
South Korea	252,799	1,672,353	12.2
Colombia	1,061,716	611,011	22.2
Cuba	1,084,094	479,554	9.8
Panama	1,229,607	331,358	31.5
Canal Zone	17,165	1,436,424	---
Mexico	677,417	758,039	12.8
Belgium	706,125	794,153	1.9
France	334,326	941,959	0.9
Italy	185,766	1,032,002	0.6
Formosa	307,414	823,642	8.9
El Salvador	207,868	870,014	68.1
Poland	843,564	75,297	2.9
Trinidad/Tobago	680,661	108,642	2.3
South Vietnam	-----	772,063	10.2
Nicaragua	166,801	494,675	55.1
Brazil	387,816	240,668	1.3
Puerto Rico	100,397	514,360	---

(Continued on following page)

[1] Countries are ranked in accordance with total of origin and destination cargoes in Fiscal Year 1969. Canal per cent of country's total oceanborne trade is based upon data contained in the United Nations Statistical Yearbook, 1970.

TABLE 2 (Cont'd)

PANAMA CANAL USERS, FISCAL YEAR 1969[1]

Country	Long Tons of Commercial Cargo Origin	Destination	Per Cent of Country's Total Oceanborne Trade
Spain/Portugal	108,216	452,971	0.8
Jamacia	427,746	113,646	4.0
China	343,290	192,271	2.5
Costa Rica	276,139	237,150	30.9
Guatemala	74,396	407,349	30.9
Indonesia	66,578	413,416	1.8
Hong Kong	193,990	230,662	3.7
East Germany	355,160	48,179	4.2
French Oceania	130,498	246,157	–––
Sweden	164,508	195,267	0.5
British Oceania	319,320	38,007	–––
British East Indies	188,277	122,919	–––
Netherlands Guiana	288,765	––––	–––
Honduras	210,642	20,602	13.6
USSR	187,477	32,731	0.2
Thailand	68,656	151,272	1.7
North Korea	57,493	127,350	12.1
Denmark	52,777	128,345	0.6
West Indies Associated States	134,371	40,023	–––
Norway	103,574	66,836	0.3
Finland	158,050	––––	0.6
Guyana	140,418	––––	2.8
Yugoslavia	11,491	128,840	1.1
Argentina	36,886	56,355	0.5
South Africa	––––	92,317	0.4
Irish Republic	––––	75,831	0.7
Haiti and Dominican Republic	10,004	59,844	1.6
Rumania	62,867	––––	0.9
Israel	––––	56,452	0.9
Libya	––––	40,278	–––
Greece	––––	32,423	0.2
Lebanon	––––	26,380	0.1
Morocco	––––	12,995	0.1
Mozambique	––––	10,100	0.1
British Honduras	1,636	––––	0.8
All Others	2,311,328	3,209,726	0.8
TOTAL	101,391,132	101,391,132	

CHAPTER III

POTENTIAL CANAL TRAFFIC AND REVENUES

Canal traffic forecasts are required to determine (a) when the present canal will become incapable of meeting estimated demand for transits and (b) whether a new sea-level canal could be financed from toll revenues. Legislation authorizing a sea-level canal, and the subsequent detailed planning and construction, would require approximately 15 years, and 60 years or more thereafter might be required for amortization. This period of 75 years into the future is excessive for economic forecasting; hence, the estimates of potential canal traffic and revenues described herein of necessity incorporate assumptions and judgments.

Previous Canal Traffic Forecasts

Many forecasts have been made of traffic through the Panama Canal. Figure 6 compares actual Panama Canal experience with forecasts by Hans Kramer in 1927; Norman Padelford in 1944; Roland Kramer in 1947; Stanford Research Institute in 1958, 1964 and 1967; and Gardner Ackley in 1961. These forecasts have almost without exception soon been exceeded by the traffic which subsequently developed. As the forecast periods became history, unforeseen new commodity movements appeared in ever-increasing proportions of the total tonnages passing through the canal.

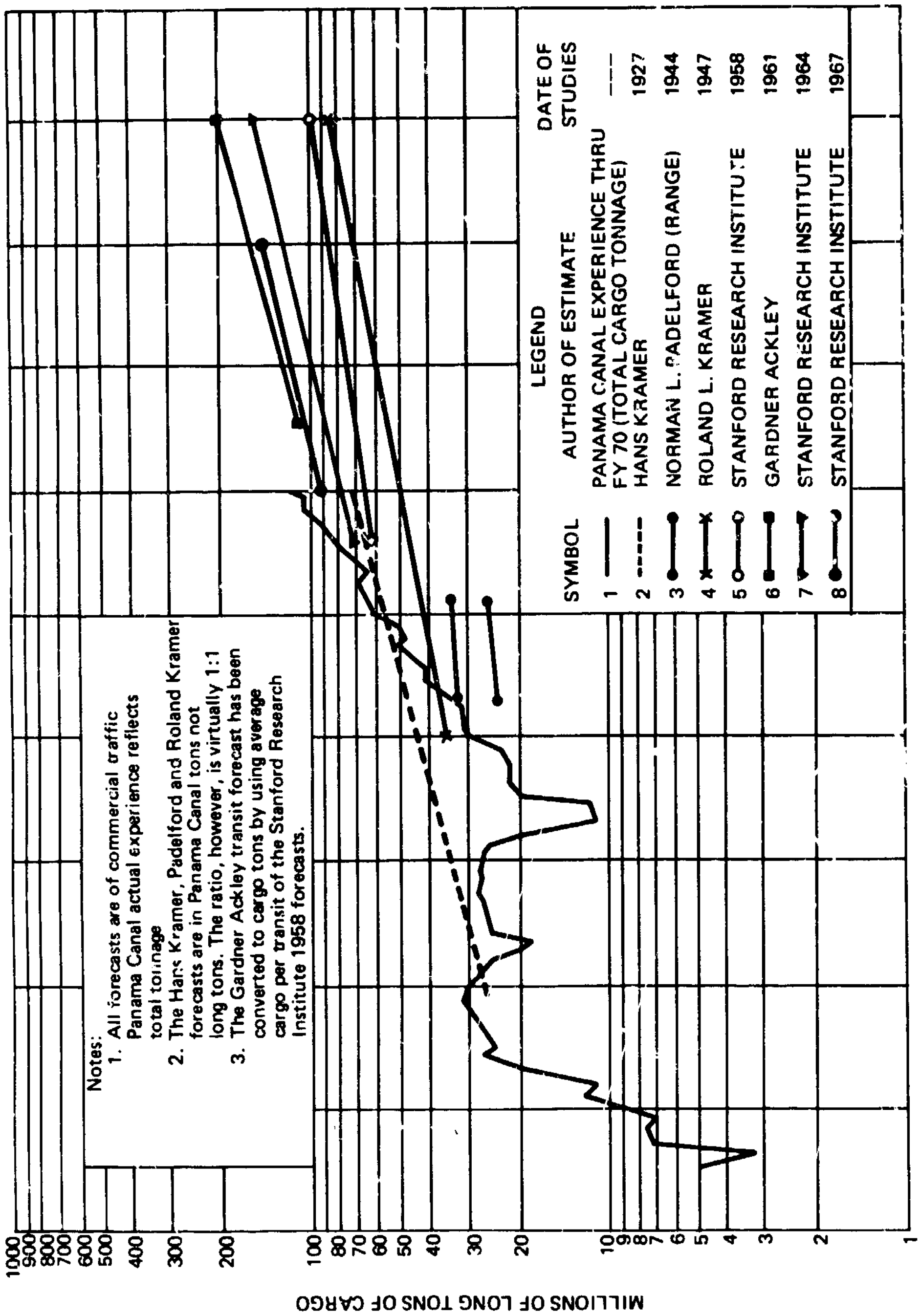
The Economic Research Associates, Inc., Forecast

The Shipping Study Group, in its report to the Commission, did not estimate future traffic through the existing canal; it limited its considerations to the potential traffic through an unrestricted canal. However, early in 1970 a traffic forecast through 1985 for the present canal was independently developed by Economic Research Associates, Inc. (ERA) under a contract with the Panama Canal Company (Figure 7). It arrived at a projection of potential canal traffic essentially the same for the 1970-1985 period as in the Commission's forecasts, described later in this chapter, produced by a different methodology. ERA also forecast the division of potential traffic between the present canal and alternate routes. As will be shown later in this Chapter, the ERA forecast provides a logical basis for estimating the saturation date of the present canal if no sea-level canal is built.*

Capacity of the Present Canal

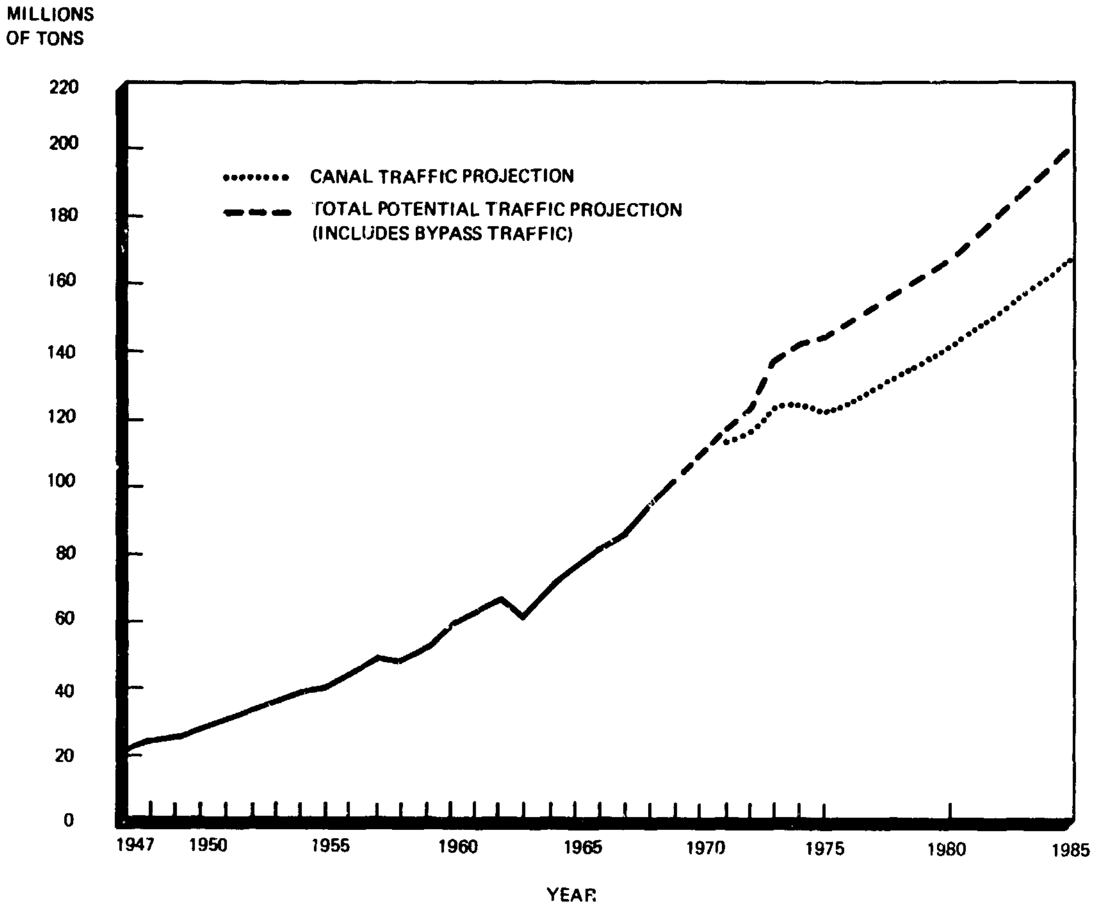
The average amount of commercial cargo per ship transiting the Panama Canal increased slowly from approximately 4,000 to 5,500 long tons from 1920 to 1960. During the past ten years, however, there was a rapid increase: 6,470 long tons per transit in 1965; 7,710 long tons per transit in 1969; and 8,366 long tons per transit in 1970. The average amount of cargo per ship passing through the Panama Canal in future years will certainly not lessen; it

*Saturation date is the year in which the number of transits through the canal reaches the maximum number that can be passed through the locks, estimated to be 26,800 per year.



COMPARISON OF PREVIOUS PANAMA CANAL TRAFFIC FORECASTS AND PANAMA CANAL ACTUAL TOTAL CARGO TONNAGE EXPERIENCE

FIGURE 6



PROJECTED PANAMA CANAL COMMERCIAL
AND BYPASS TRAFFIC, LONG TONS OF CARGO
Source: Economic Research Associates

FIGURE 7

should continue to increase as more and more intermediate sized tankers and large bulk carriers are used to carry crude oil and petroleum products and dry bulk commodities through the Panama Canal. The indications from this 10-year trend are that the average will be 9,500 long tons per ship by the time traffic reaches 150 million long tons of cargo per year, and at least 12,000 tons per transit when 250 million tons of commercial cargo per year are carried through the Panama Canal.

The numbers of commercial transits of an interoceanic canal with respect to the amount of commercial cargo in the future, as variously estimated, are shown in Table 3.

TABLE 3

COMMERCIAL OCEAN TRANSITS OF AN ISTHMIAN CANAL RELATIVE TO COMMERCIAL OCEAN CARGO IN YEAR

Annual Cargo Transited (Millions of Long Tons)	Shipping Study Report[1] 46 Per Cent Of Tonnages In Freighters	25 Per Cent Of Tonnages In Freighters	ERA Report	Historical Trend
111	14,700	14,700	13,500	13,500
125	15,800	15,100	14,000	14,400
150	18,300	16,500	16,100	15,900
175	20,500	18,000	----	17,300
200	22,900	19,300	----	18,700
225	25,000	20,700	----	20,000
250	----	21,900	----	21,400
300	----	23,600	----	24,200
350	----	25,500	----	----

[1] Annex IV, Study of Interoceanic and Intercoastal Shipping, transit data are related to forecasts of total potential tonnage, including all categories of traffic that transit the Panama Canal. This table relates to commercial ocean traffic only.

The Panama Canal Company has determined that 26,800 transits per year of all classifications could be accommodated by completion of improvements now underway and by augmentation of the water supply for lock operation. There generally have been less than 1,500 noncommercial transits per year, although the total did exceed 2,000 in the years of United States military actions in Asia. The effective transit capacity of the existing Panama Canal may thus be taken to be 25,000 commercial cargo ships per year. The corresponding upper limit of capacity of the Panama Canal, expressed in long tons of commercial cargo per year, has been estimated by the Shipping Study Group to be:

–Forecast assuming 46 percent of tonnages moving in freighters and an average of 8,800 tons per transit: 220 million long tons

–Forecast assuming 25 percent of tonnages moving in freighters and an average of 12,400 tons per transit: 310 million long tons

If the average size of the ships transiting the Panama Canal continues to increase at the rate that has prevailed for the past 10 years, the capacity at the saturation level will be at least 300 million long tons per year.

It may be inferred from estimates of probable bypass traffic during the next 15 years that the demand on the Panama Canal (if it is not superseded) will be approximately 50 million tons less in the year 2000 than the traffic that would pass through an unrestricted canal. The corresponding demand on the Panama Canal would thus be approximately 300 million long tons in the year 2000 if the potential forecast of the Commission were realized or 200 million long tons if its low forecast prevails. These estimates are consistent with the Shipping Study Group analysis of the economics of alternatives of the existing canal (Annex IV).

It is apparent from this analysis of its capacity and the projections of future demand that the Panama Canal can accommodate the demand for transits by ships of the size that can pass the existing locks for at least 20 years and more probably to the end of this century.

Forecast of World Trade Growth

A 1968 study of world oceanborne trade by Litton Systems, Inc. forecast that the growth of aggregate ocean cargo tonnages would slow from the current 7.2 per cent annual rate to around 4 per cent by the end of the century and ould continue to grow thereafter at approximately that rate. For the past 20 years the Panama Canal portion of total cargoes moving in ocean trade each year has been consistent, varying less than one percentage point above or below 5.1 per cent of the total. A forecast based upon this relationship, using the Litton forecast of world trade, would justify high expectations for a sea-level canal. However, a projection of potential canal traffic growth into the future at the exponential rates of the Litton Study reaches economically questionable levels toward the end of the century and unrealistic levels thereafter.

The Commission's Forecasts

The traffic growth pattern of the Panama Canal (Figure 6) shows a rapid increase in the years immediately after its opening in Fiscal Year 1915 followed by a levelling off to insignificant growth during the depression and war years from 1929 to 1945. Since World War II, however, there has been sustained growth, and there are no indications of a marked decline in this growth in the near future. The data are given in detail in Table I' of Annex IV and are summarized in Table 4 of this report. Much of the rapid increase in Panama Canal traffic in recent years stemmed from trade with Japan, as shown in Table 5.

Two long-range forecasts of traffic through a non-restricted Isthmian canal, made by the Shipping Study Group, are given in Table 6 and shown graphically in Figure 8. The forecast of potential canal tonnages recommended to the Commission was in essence a summation of separate estimates of canal traffic originating in 15 different regions, based in each case on the historical relationship between such traffic and the respective Gross Regional Product (GRP) and on extrapolation of that GRP through the year 2000. This

TABLE 4

GROWTH OF PANAMA CANAL TRAFFIC

Fiscal Year	Total Transits Number	Total Transits Cargo Million Tons	Commercial Ocean Transits Number	Commercial Ocean Transits Cargo Million Tons
1915	1,108	4.9	1,058	4.9
1920	2,777	9.7	2,393	9.4
1925	5,174	24.2	4,592	24.0
1930	6,875	30.2	6,027	30.0
1935	6,369	25.4	5,180	25.3
1940	6,945	27.5	5,370	27.3
1945	8,866	19.4	1,939	8.6
1950	7,694	30.4	5,448	28.9
1955	9,811	41.5	7,997	40.6
1960	12,147	60.4	10,795	59.3
1965	12,918	78.9	11,834	76.6
1970	15,523	118.9	13,658	114.3

TABLE 5

INFLUENCE OF JAPAN TRADE
Millions of Long Tons

Year	Total Commercial Cargo in Year	Japan Trade	Other Cargo
1956	45.1	7.2	37.9
1957	49.7	10.2	39.5
1958	48.1	8.5	39.6
1959	51.2	9.1	42.1
1960	59.3	12.2	47.1
1961	63.7	15.3	48.4
1962	67.5	17.8	49.7
1963	62.2	15.4	46.8
1964	70.6	19.8	50.8
1965	76.6	21.4	55.2
1966	81.7	24.5	57.2
1967	86.2	28.9	57.3
1968	96.5	38.1	58.4
1969	101.4	41.0	60.4
1970	114.3	51.4	62.9

TABLE 6

CARGO TONNAGE FORECASTS FOR AN UNRESTRICTED ISTHMIAN CANAL

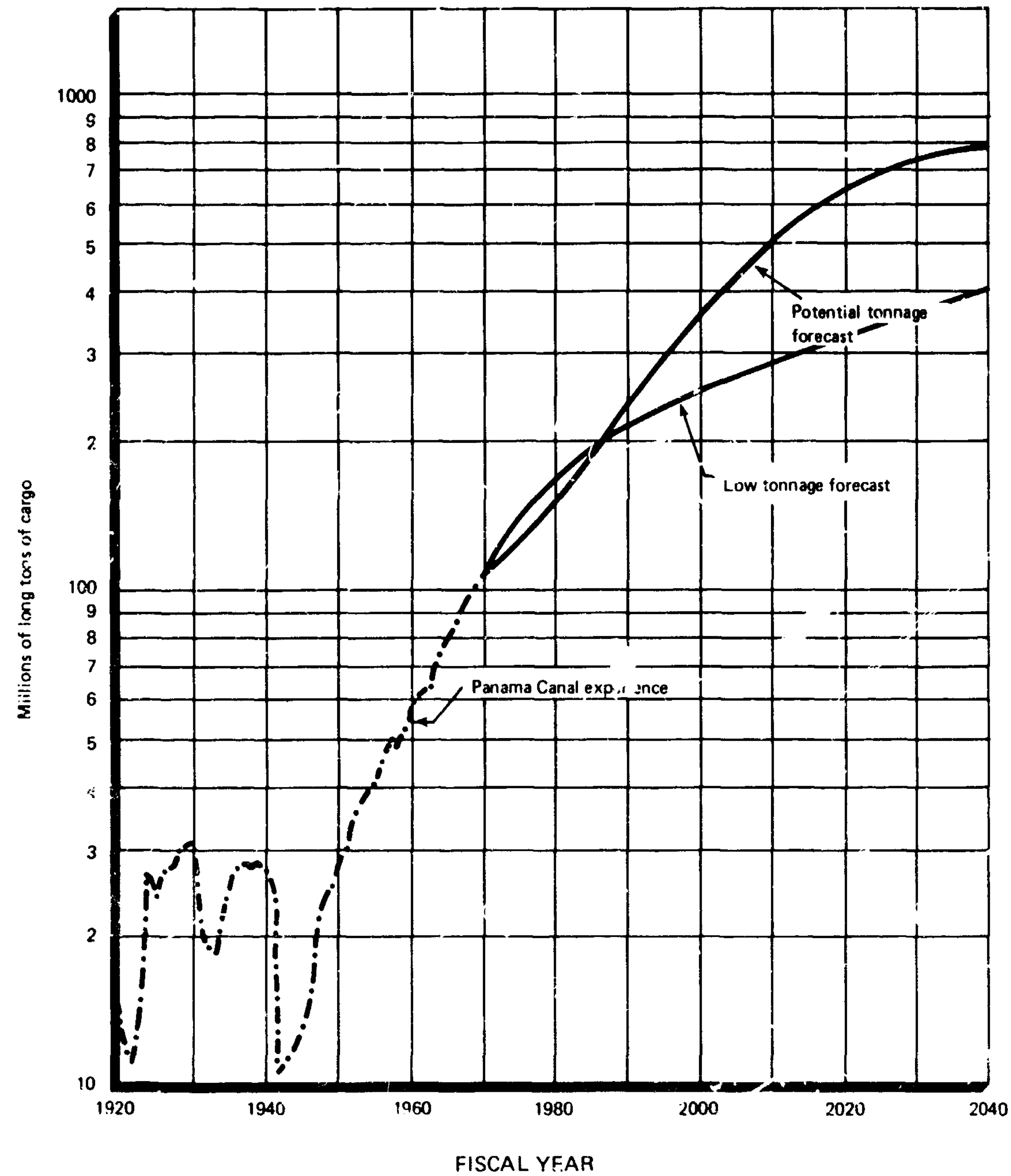
Millions of Long Tons Per Year Including Allowances for Non-Commercial Traffic

Fiscal Year	Potential Tonnage Forecast	Low Tonnage Forecast
1975	125	141
1980	157	171
1985	194	197
1990	239	218
1995	293	237
2000	357	254
2005	429	272
2010	503	290
2015	577	307
2020	643	325
2025	700	344
2030	743	363
2035	770	383
2040	778	403

forecast was accepted by the Commission for planning purposes. The other forecast was developed by isolating the traffic to and from Japan from other commercial traffic and then making separate forecasts for Japan trade and for the remainder of all potential traffic. The Commission accepted this lower forecast for evaluation of the financial risk that could stem from construction of a sea-level canal.

Ship Sizes and Potential Canal Transits

The Panama Canal satisfied all demands for shipping between the Atlantic and the Pacific Oceans from the start of operations in August 1914 until recent years when very large tankers and bulk carriers began to be built. In 1970 there were approximately 1300 such ships afloat and under construction or on order which could not pass through the existing locks under any circumstances because of beam width and approximately 1750 others that could not pass through fully laden at all times because of draft limitations. All of the former and most of the latter are now being used, or will be used, on trade routes that do not involve the Panama Canal, such as shipments of petroleum from the Middle East to Europe and iron ore from Australia to Japan. On the other hand, if it were not for the physical limitations of the Panama Canal, some of these bulk carriers would undoubtedly be used on canal routes. Distinction must therefore be made between the traffic that the



CARGO TONNAGE FORECASTS
FOR A NON-RESTRICTED ISTHMIAN CANAL

FIGURE 8

Panama Canal will be called upon to handle and the potential traffic that an unrestricted sea-level canal might attract.

The dimensions of the existing locks of the Panama Canal preclude the passage of ships larger than 65,000 deadweight tons* (DWT) when fully laden. This size limitation and the time required for passage of ships through the locks now impose few restraints on free movement of oceanborne commerce, but both will become progressively more restrictive as the average size of the ships and the number of transits increase. Few general cargo vessels are likely to be built that could not pass through the present canal. Approximately 1 per cent of the bulk carriers now in service are larger than 65,000 DWT, but by the year 2000 about 10 per cent are expected to be. Only 7 per cent of the tankers now afloat cannot transit the Panama Canal, but it is predicted that within 30 years more than half of the tankers in the world fleet will be too large to do so. Table 7, developed by the Commission's Shipping Study Group, lists the projected average sizes of ships that would use a future Isthmian canal, considering a range of maximum size ships to be accommodated.

TABLE 7

AVERAGE DWT PROJECTIONS

Ship Type	Maximum Ship Size	1970	1980	1990	2000	2020	2040
Freighter	All Limits	10,800	11,500	12,200	13,000[1]	14,600	16,500
Bulker	65,000	27,800	33,900	39,800	44,400	48,800	52,000
	100,000	28,000	35,900	43,000	50,000	61,500	69,000
	150,000	28,000	36,000	43,700	51,600[1]	65,800	81,000
	200,000	28,000	36,200	44,100	52,000	67,000	84,000
	250,000	28,000	36,200	44,100	52,200	67,200	85,000
Tanker	65,000	19,200	27,700	33,000	36,000	37,000	37,000
	100,000	20,000	31,800	41,600	49,200	54,300	56,000
	150,000	20,100	33,000	44,800	55,000[1]	66,500	74,600
	200,000	20,100	33,300	45,500	56,600	71,000	83,200
	250,000	20,100	33,300	46,000	57,500	72,200	87,200

[1] Example: In a canal that could accommodate ships up to 150,000 DWT the average freighter in the year 2000 would be 13,000 DWT; dry bulker, 51,600 DWT; and tanker, 55,000 DWT.

Panama Canal ship mixes and likely variations in canal ship mixes in the future are discussed in detail in Annex IV, Study of Interoceanic and Intercoastal Shipping. In recent years, freighters have carried 46 per cent of the cargo tonnage, dry bulkers (some also carried liquid cargo) 37 per cent, and tankers 17 per cent. It is anticipated that the proportion of freighter tonnage will diminish progressively as more and more large bulk

*Deadweight tonnage of a ship is its fully laden capacity in long tons (2240 pounds), including cargo, fuel, and stores, but excluding the weight of the ship itself.

carriers come into use. Since any specific forecast of transits for many years in the future would have little reliability, transit requirements were calculated for a range of cargo mixes: a maximum of 46 per cent freighter tonnage; a minimum of 25 per cent of freighter tonnage. The resulting range of transit possibilities is shown in Table 8. Figure 9 graphically portrays the range of possible transits for the potential tonnage forecast, used by the Commission for sea-level canal capacity planning It is probable that future sea-level canal transits would remain above the middle range during the remainder of this century and fall into the lower portion in later years.

TABLE 8

PROJECTED SEA-LEVEL CANAL TRANSITS
(150,000 DWT Maximum Ship Size Capacity)

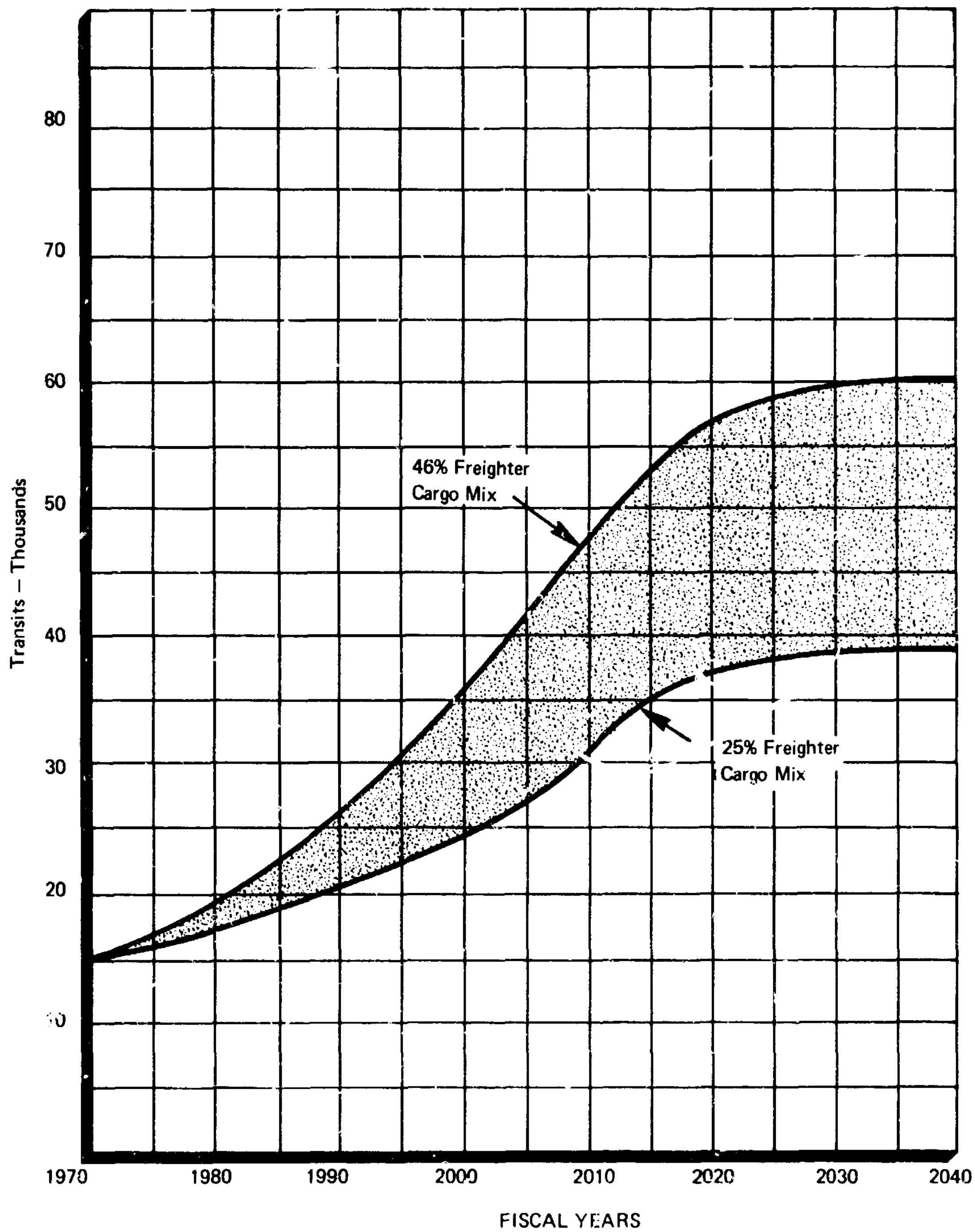
	Potential[1] Tonnage Forecast			Low[2] Tonnage Forecast		
Year	2000	2020	2040	2000	2020	2040
Tankers	2,252	3,350	3,618	1,602	1,693	1,874
Dry Bulkers	5,652	7,983	7,846	2,565	2,574	2,593
Freighters	16,745	26,854	28,751	21,921	24,975	27,403
Totals	24,649	38,187	40,215	26,088	29,242	31,870

[1] Assumes most tonnage growth will be in bulk cargoes and current Panama Canal ratio of 46 per cent of cargo tonnages transiting in freighters will decline to 25 per cent by 2000.

[2] Assumes uniform growth rate of freighter and bulk cargo tonnages with 46 per cent of tonnages continuing to transit in freighters through the forecast period.

Estimated Sea-Level Canal Revenues at Current Toll Rates

A canal capable of accommodating large bulk carriers will attract more bulk cargoes than the present canal. Therefore, revenue estimates must take cognizance of the projected range of future possibilities: the present Panama Canal cargo mix in which 46 per cent of tonnages move on freighters, 37 per cent on dry bulk carriers, and 17 per cent on tankers; and a possible future mix of 25 per cent freighter cargoes, 58 per cent dry bulk cargoes, and 17 per cent tanker cargoes. The average revenue per ton of cargo transited on dry bulk carriers is the lowest since they usually transit fully laden and have relatively few ballast transits. The revenue from tankers is higher because of their higher ratio of ballast transits. The revenue per ton for freighters is highest; they have few ballast transits but usually carry bulky, light cargoes and are often not fully laden.



ISTHMIAN CANAL TRANSITS BASED ON POTENTIAL TONNAGE FORECAST

FIGURE 9

Because the Panama Canal tolls are assessed on the basis of measurement tons (100 cubic feet of cargo capacity), revenues per weight ton of cargo vary widely. The average revenue per weight ton of cargo passing through the canal during the past 20 years has fluctuated between 80 and 90 cents per long ton of commercial cargo with a trend toward the higher amount. Continuation of this upward trend of the average toll per cargo ton carried through the Panama Canal is indicated by the findings in the recent report of the Economic Research Associates to the Panama Canal Company. This trend would probably reverse whenever a sea-level canal became available for use by ships that cannot pass the locks of the present canal, because of the relatively low revenue per cargo ton realized from such ships. Therefore, the average toll per long ton of commercial cargo that would be carried through a sea-level canal can be expected to decrease as the volume of traffic becomes greater and larger and larger ships come into service. A probable relationship between such traffic and the average toll is shown in Table 9.

The potential revenues from tolls and toll credits at these average rates per cargo ton are shown in Table 10 for the traffic forecast recommended by the Shipping Study Group and for the lower forecast described in the report of that group. It is assumed, as has been generally true in the past, that the average toll per commercial cargo ton is a fair measure of toll credits of non-commercial transits.

Maximum Sea-Level Canal Toll Revenues

Three independent studies of potential revenue from the present canal have been made in recent years. These are the Arthur D. Little Company Study in 1966 for the United Nations Special Fund, the Stanford Research Institute's Study in 1967 for the Panama Canal Company, and the Panama Canal Company's 1970 Study in connection with its evaluation of the Intergovernmental Maritime Consultative Organization's proposed Universal Measurement Tonnage System.

The Arthur D. Little Study evaluated the movements of major commodities through the canal in comparison with shipping costs between the same sources and destinations via alternate routes. The study concluded that, for the short run, an upward revision of the present tolls could double or triple gross revenues. However, extensive readjustments would take place over the long run with loss of much of the potential traffic.

The Stanford Research Institute's (SRI) study involved a judgmental determination of the responses of commodity movements to toll increase by comparing the estimated costs of alternatives to the canal. It concluded that across-the-board increases up to 25 per cent would have little effect on traffic, but larger increases would discourage traffic growth. A 100 per cent increase would cause traffic growth to cease entirely and perhaps even cause traffic to decline. However, the study concluded that the maximum revenues could be obtained over the long run by selective toll increases on a commodity basis, ranging from 25 per cent to 150 per cent.

The findings of the Panama Canal Company's 1970 Study were generally consistent with those of the SRI Study. The 1970 Study concluded that maximum toll revenues could be obtained through selective increases averaging approximately 50 per cent. It was estimated that this would produce revenues about 40 per cent greater than would be produced by continuation of the present system.

TABLE 9

ESTIMATED SEA-LEVEL CANAL REVENUE RELATIVE TO TOTAL CARGO TONNAGE

$0.90 per Laden Panama Canal Ton
$0.72 per Ballast Panama Canal Ton

Cargo Millions of Long Tons in Year	Average Toll	Toll Revenue Millions of Dollars
200	$0.848	170
300	0.812	244
400	0.777	311
500	0.777	389
600	0.777	466
700	0.777	544
800	0.777	622

TABLE 10

FORECASTS OF SEA-LEVEL CANAL REVENUES

$0.90 Per Laden Panama Canal Ton
$0.72 per Ballast Panama Canal Ton

Fiscal Year	Potential Tonnage Forecast $ Millions	Low Growth Forecast $ Millions
1990	205	185
2000	290	215
2010	391	235
2020	500	264
2030	577	282
2040	605	313

It is apparent from these studies that it would be necessary to do away with the present Panama Canal toll structure to realize the maximum potential revenues in an Isthmian canal. This toll structure, however, which does not discriminate among types of cargo, is established by law and has the advantages of simplicity of administration, conformity with systems used in many other canals and ship facilities, and established acceptability to canal users. Furthermore, this schedule is currently producing revenues adequate to meet

legislatively established obligations of the Panama Canal Company.

The Commission recognizes that United States law requires public hearings before canal tolls can be increased and that the views of the Congress, canal users, and others would have to be considered in setting tolls in a sea-level canal. However, in view of the large capital investment required for a sea-level canal (or for additional locks for the present canal) and possible future increases in host-country compensation, the Congress may determine that higher revenue objectives are warranted. The Commission's study of the potential for toll increases and higher revenues was directed to the practical options available. These are set forth in detail in Annex IV, Study of Interoceanic and Intercoastal Shipping. In general, it was found that:

1. The A.D. Little Company, the Stanford Research Institute, and the Panama Canal Company studies of the lock canal are applicable to an analysis of the revenue potential of a sea-level canal.
2. The alternatives to the use of any Isthmian canal place an upper limit on the charges it can impose for its services. These alternatives include:
   a. Alternative ship routing to avoid the canal, and alternative ship sizes in conjunction;
   b. Transithmian pipelines for petroleum and dry bulk materials transported in liquid slurry form;
   c. The land bridge concept in which rail movement in the United States and Canada substitutes for canal routing;
   d. Air transport; and
   e. Substitute sources and markets.
3. The potential bulk commodity traffic of the sea-level canal is very large, but the alternatives to the canal limit the ability to increase tolls on these commodities above present Panama Canal tolls.
4. The tolls on other categories of cargo could be increased on a selective basis in varying amounts up to 300 per cent without exceeding the cost of available alternatives.
5. The toll system that would produce the greatest revenue without discouraging traffic growth is one with rates based upon the value to each user. The direct cost of rendering the services would determine the minimum level for a tolls charge, and the cost of the most attractive alternative would determine the maximum charge. If permitted to use such a pricing structure, a sea-level canal could attract almost all potential traffic from alternative routes and transportation modes.

The findings of the Shipping Study Group as to the maximum potential revenues of a sea-level canal may be summarized as follows:

- The potential traffic level of a sea-level canal is not likely to be achieved with a new canal limited to ships of 100,000 DWT or less. It is most likely to be achieved by a canal with a capacity to transit ships of 200,000 DWT or larger.
- Toll rates in a canal of adequate dimensions could be increased an average of 50 per cent in terms of current dollars by the use of a new system of tolls. This would cause some loss of potential traffic, but would produce approximately 40 per cent additonal revenue.

- In addition to the potential for increase in current dollars, average tolls could be increased at a rate approximating the average inflation of the costs of canal alternatives with little impact on the volume of traffic.
- If tolls are restructured to produce maximum revenues, provisions must be made for the variations in tolls sensitivities among commodities, ship sizes, and routes.
- A pricing system for structuring tolls designed to meet the costs of competing alternatives offers the greatest revenue potential for a sea-level canal.

CHAPTER IV

EXCAVATION BY NUCLEAR METHODS

The initial PLOWSHARE cratering experiments and engineering studies conducted from 1958 through 1962, as well as a number of applicable nuclear weapons effects tests, encouraged the hopes of the scientists and engineers involved that a practical nuclear excavation technology would soon be forthcoming. An attractive potential application then considered was the construction of a sea-level Isthmian canal; in 1963-1964 conceptual studies and research in the new technology were extended to include this objective. Two Isthmian canal routes, Route 17 in Panama and Route 25 in Columbia, having sparse populations, remoteness from population centers, and apparently favorable topography, appeared to meet the requirements of the embryonic technology.

Preliminary engineering estimates, made without on-site investigations, put nuclear canal construction cost for Route 17 as low as $747 million – about one-third the then estimated cost of conventional construction on Route 14. Route 25 was estimated to cost more because only a portion was thought suitable for nuclear excavation. However, it was recognized that the potential economies were contingent upon proof of the feasibility of nuclear excavation by further research and experimentation and also upon favorable results of comprehensive physical surveys of the engineering and nuclear safety features of the selected routes.

There was optimism in 1964 that on-site studies of the routes and the planned program of additional nuclear cratering experiments would establish the feasibility and desirability of nuclear excavation, although the magnitude of the technical and political obstacles to nuclear excavation was recognized by President Johnson's advisers. Further, the United States was being pressed by Panama to revise the 1903 Treaty. The urgency of determining the feasibility of a sea-level canal was then deemed to warrant proceeding with on-site route investigations while carrying out the additional nuclear cratering experiments needed to develop a practical nuclear excavation technology.

The authorizing legislation requested by the President and approved by the Congress contemplated extensive data collection on the two most promising nuclear routes, 17 and 25. Only limited field investigations of the routes for conventional excavation were provided for as the available data were thought to be sufficient for feasibility studies. No field work was planned for Route 8 inasmuch as evaluations based upon available data showed it to be less suitable than other routes under consideration. The original authorization for the planned studies was $17.5 million. This amount was later augmented to $24 million, in part to expand the investigation of routes suitable for conventional excavation. The actual expenditure was $22.1 million, of which approximately $17.5 million was devoted to the nuclear routes, $3.0 million to the conventional routes, and $1.6 million to all other activities.

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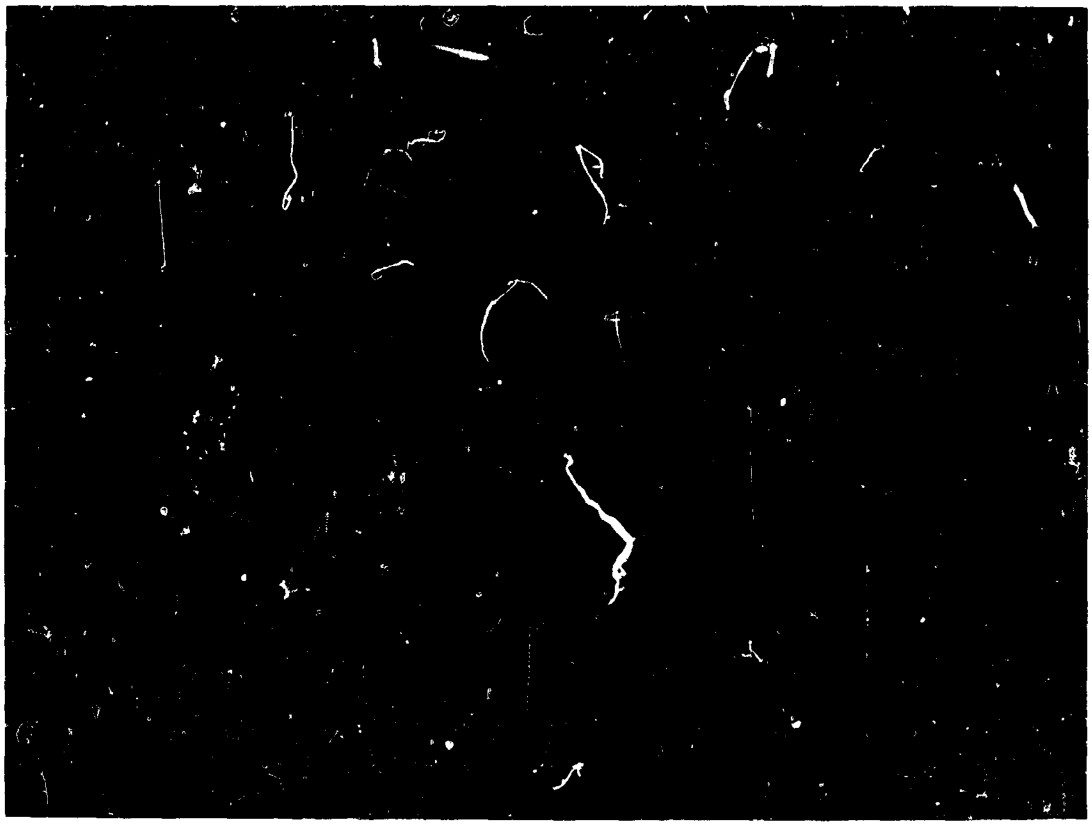

SEDAN, July 6, 1962, 100 Kiloton – The Thermonuclear explosion occurred 635 feet below surface and excavated a crater about 1200 feet in diameter and about 320 feet deep with a volume of about 6.5 million cubic yards.

FIGURE 10

Nuclear Excavation Technology

In 1964 knowledge of nuclear cratering physics was limited to single craters in alluvium and rock. Row crater experiments had been conducted with chemical explosives only. However, extensive knowledge of the radioactivity, fallout, seismic, and air blast phenomena associated with nuclear excavation operations was available from a wide variety of nuclear tests.

It had been estimated in prior Isthmian canal studies that the deep cuts through the Continental Divide sections of the routes would require salvo yields in the tens of megatons (Mt).* Such levels were considered troublesome, particularly from the ground motions that might be induced. It was recognized in these studies that radioactivity from fallout could require extensive evacuation precautions and present problems under the restrictions of the Limited Test Ban Treaty. There was confidence, however, that the radioactivity effects could be held to insignificant levels.

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*Nuclear explosive equivalent of one million tons of the chemical explosive, trinitrotoluene (TNT).

The BUGGY I crater approximately 860 feet long, 250 feet wide, and 65 feet deep produced by the simultaneous detonation of five nuclear explosives of approximately 1 kiloton each on March 12, 1968. The explosives were buried 135 feet deep and spaced 150 feet apart in hard rock on the U.S. Atomic Energy Commission's Nevada Test Site. The arrow points to a pick-up truck.

FIGURE 11

When the sea-level canal investigation was initiated in 1965, it was expected that development of the nuclear excavation technology would be advanced sufficiently during the course of the investigation to permit determination of its feasibility for canal construction. The AEC's PLOWSHARE program in nuclear excavation was expanded in order that development of the technology would be phased with the Canal Study Commission's timetable. A program of some six to eight nuclear tests was considered the minimum necessary to develop the technology.

Complementary theoretical and laboratory tests and studies were also programmed and carried out. These related to all aspects of nuclear excavation, including the development of clean devices and the probable behavior in cratering of the different materials not so far tested – rock, saturated rock, and clay shales as found on the Isthmian routes.

Political and budgetary constraints caused the planned PLOWSHARE nuclear excavation program to move slowly. Although the Canal Study Commission's reporting date was extended from June 30, 1968 to December 1, 1970, only three tests were carried out during the Commission's investigation. The data from them materially assisted the complementary

United States Air Force CH-3 Helicopter Lifting a Drilling Mast on Route 17

FIGURE 12

studies and provided corroborative data at yields approaching usefulness for practical excavation projects. The higher yield nuclear cratering experiments of the magnitude required for the Isthmian canal excavation, however, remain to be carried out.

Engineering and Nuclear Operations Surveys

The engineering and nuclear operations surveys of Routes 17 and 25 were carried out essentially as planned except for unavoidable delays. A field office in the Canal Zone and base camps on each route were established. The latter were augmented by small satellite

camps along the alinements. The personnel involved numbered more than 800 at the height of field activities.

Four weather stations were built and operated in Panama and Colombia to acquire the weather data needed for prediction of the effects of nuclear operations and for other purposes. Very high altitude air studies were conducted, using balloon and rocket-borne instruments. Surveys of existing buildings and other structures within projected areas of significant ground motion were made to estimate structural response and damage. Bioenvironmental studies in the various radioecological systems were carried out by scientists of different fields (marine, terrestrial, agriculture, forest, freshwater, etc.).

The engineering data program included topographic surveys to establish the preferable alinements and their elevations. The surface geology along each route was mapped and subsurface borings were carried out to confirm or correct geological interpretations. Rainfall and stream flow were measured. People were counted.

As usual, in such preliminary surveys there are areas where more data and longer collection periods would have been desirable. The data obtained, however, provide a basis for a number of findings not previously possible.

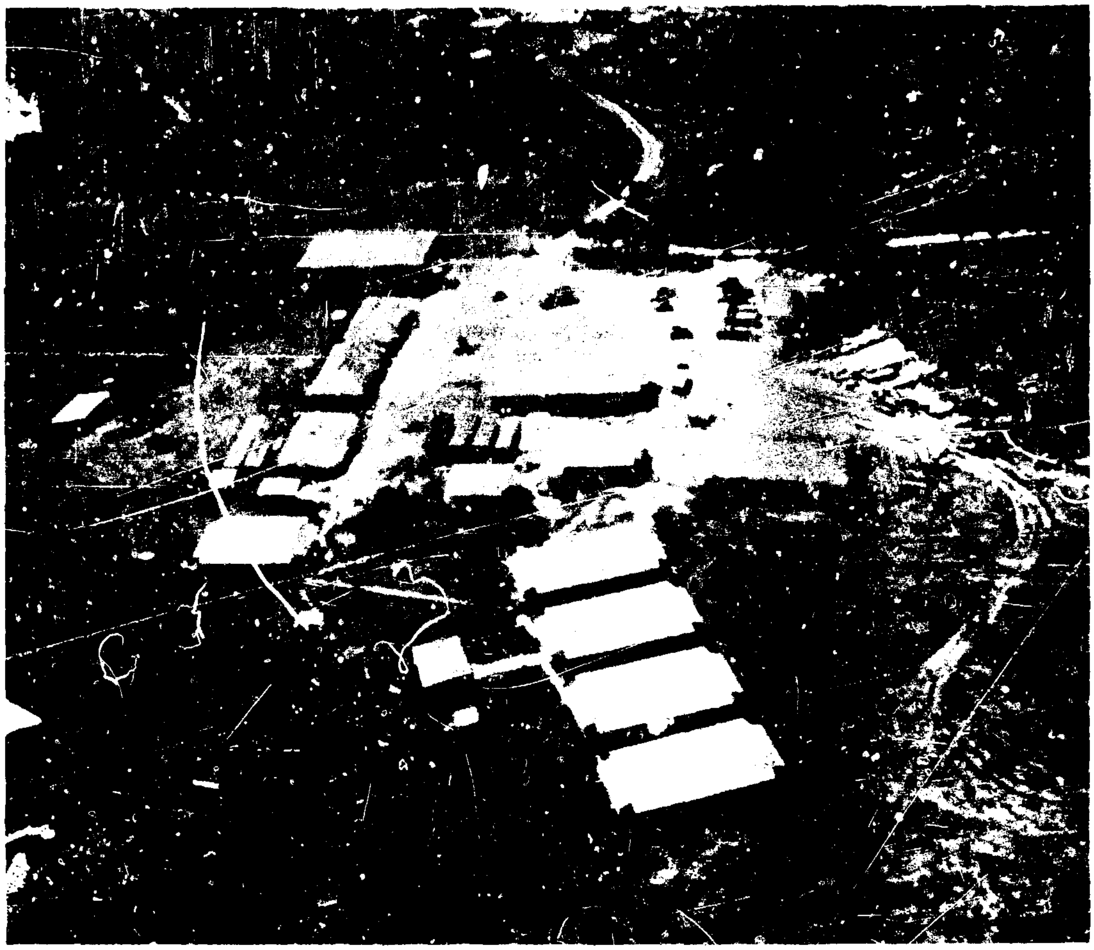
Detailed analyses of the nuclear excavation technology and its potential application to specific canal routes are contained in Annex V, Study of Engineering Feasibility, and its appendices. Several of the technical evaluations developed from the surveys of Routes 17 and 25 are summarized below. Discussions of the unique political, military, and economic aspects of these routes are contained in Chapter VII, Analysis of Alternatives.

Route 17

1. Geological drilling on Route 17 found competent rock along approximately three-fifths of the 50-mile route. Hard materials predominate throughout the 20-mile Continental Divide reach on the north and for 10 miles through the Pacific Hills on the south. The center 20 miles through the Valley of the Chucunaque River, however, consist largely of clay shales. This material, if excavated to steep slopes, softens and slides as it weathers. Slopes as flat as one unit of vertical rise for each 12 units of horizontal measurement probably are needed for long-term stability in the deepest excavation. Such slopes cannot be produced by single-row explosive excavation, and the chemical explosive experiments conducted thus far indicate that it is unlikely that multiple-row techniques can be developed to produce flatter slopes. For this reason, cost estimates had to be based on the assumption that the center portion of Route 17 would require conventional excavation.
2. The portions of Route 17 which appear to be suitable for nuclear excavation are currently estimated by the United States Army Engineer Nuclear Cratering Group to require about 250 separate explosives with a total yield of 120 megatons. They would be fired in some 30 salvos of varying total yields over a period of 3 years or longer. The largest salvo would have a total yield of 11 megatons. These estimates are approximations only, based upon the limited route data available and calculated nuclear explosive effects determined by extrapolation of low-yield experimental data available in 1969. The AEC is confident that these estimates could be reduced, both in number of explosives and in total yield required.

Rcute 17 centerline trail through the Chucunaque Valley

FIGURE 13



Site survey base camp at Santa Fe Ranch, Route 17

FIGURE 14

3. Fallout predictions based upon meteorological conditions in the vicinity of Route 17 indicate that a land area of approximately 6,500 square miles containing an estimated 43,000 persons would have to be evacuated during the period of nuclear operations and for several months thereafter. This includes most of the area that might be affected by ground shock or air blast, but precautions against glass breakage and other damage in built-up areas would be required over a large area extending out approximately 300 miles from the route. The AEC is confident, however, that a significant reduction in the size of the area affected is possible.
4. Tidal currents in a partially nuclear excavated sea-level canal on Route 17 without tidal checks would reach 6.5 knots in the conventional section.

Route 25

1. Geological drilling found competent rock through the Continental Divide reach at the Pacific end of Route 25. This constitutes approximately 20 miles of the alinement investigated. The greater portion of this 100-mile route passes through

alluvial material in the flood plain of the Atrato River. This reach is not suitable for nuclear excavation, but is well suited for economical hydraulic dredging.

2. The portion of Route 25 that appears suitable for nuclear excavation is currently estimated by the Corps of Engineers to require 150 individual explosives with a total yield of 120 megatons. They would be detonated in some 21 row salvos over a period of approximately 3 years. The largest salvo would total 13 megatons. The AEC believes these estimates, like those for Route 17, could be reduced.
3. A land area of approximately 3,100 square miles containing an estimated 10,000 inhabitants would have to be evacuated to permit nuclear operations on Route 25. As for Route 17, additional precautions would be required within a 300-mile radius during actual detonations.
4. Tidal currents in a Route 25 sea-level canal without tidal gates would reach a maximum of 3 knots.

Technical Feasibility of Nuclear Excavation of Routes 17 and 25

The Commission's Technical Associates for Geology, Slope Stability, and Foundations were asked to assist in the evaluation of the technical feasibility of nuclear excavation of Routes 17 and 25. Their report is Enclosure 2 to this report. The following extract summarizes their findings as to the feasibility of nuclear canal excavation:

> ***Feasibility of excavation by nuclear explosions is discussed in terms of: (1) the present situation, i.e., the possibility of its being used with assurance for interoceanic canal construction within the next ten years; (2) the requirements for a continuing program of nuclear testing to assure future feasibility; and (3) the possibilities of future applicability to weak rocks such as the clay shales of the Chucunaque Valley. These discussions apply exclusively to the physical development and configuration of craters which would result in a usable canal and exclude all other effects of nuclear explosions such as seismic, air blast, and radiological hazards.
>
> (1) **Present Feasibility**
>
> The Technical Associates are in unanimous agreement that the techniques for nuclear excavation of an interoceanic canal cannot be developed for any construction that would be planned to begin within the next ten years.
>
> The reasons for this opinion are:
>
> a. Extension of the scaling relations now established by tests to the much higher yield explosions is too indefinite for assured design and the "enhancement" effects due to saturated rocks and row charge effects now assumed have not been proved by large scale tests. There is a definite possibility of a major change in the mechanics and shape of the crater formed by the much higher yield explosions required for the canal excavations as compared to extrapolations from the relatively small-scale tests carried out to date.
>
> b. The effects of the strength of rock on the stability of "fall-back" slopes and the broken rock crater slopes projecting above the fall-back to the great heights required for an interoceanic canal have not yet been established.

Drilling for subsurface geological data

FIGURE 15

Therefore, the Technical Associates conclude that nuclear excavation cannot safely be considered as a technique for assured construction of an interoceanic canal in the near future.

(2) **Future Development**

The economic advantages of nuclear explosions for excavation of the very deep cuts required by an interoceanic canal are so great that the present "Plowshare" program should be continued, extended, and pursued vigorously until definitive answers are obtained. Assured application of this technology to design and construction of an interoceanic canal will require an orderly progression of tests up to full prototype size, including full-scale row charge tests, in generally comparable rock types, terrain and environment. Such a program may well require another ten to twenty years to establish whether or not nuclear excavation technology can be used with positive assurance of success for construction of a canal along Routes 17 or 25.

(3) Application to Excavation in Clay Shales

A growing body of knowledge and experience indicates that high slopes in clay shales, as in the Chucunaque Valley, or in more competent rocks underlaid by clay shales, as in parts of the existing canal, may have to be very flat for long-term stability and to avoid the danger of massive slides in the first few years after excavation. Some attempts have been made to produce such flat slopes by elaborate explosive techniques, such as over-excavation in anticipation of slides, multiple row charges, and successive series of explosions or "nibbling" techniques for application to problems such as construction of a sea-level canal across the Chucunaque Valley. The Technical Associates believe this to be a highly unpromising line of investigation with minimal chances of developing procedures that could be used with assurance in the foreseeable future.

Experimental channel excavated by chemical explosive row charges at Fort Peck, Montana

FIGURE 16

In a letter (Enclosure 3) to the Canal Study Commission near the end of the sea-level canal studies, the Chairman of the Atomic Energy Commission reported that any decision to construct a sea-level canal in the near future must be made without reliance upon the availability of nuclear excavation. He expressed the AEC's view that, given funds and authorization, the technical problems of nuclear excavation could be solved within a relatively short time; that each step which has been taken in developing nuclear excavation technology has resulted in lowering the potential risk involved; that increased understanding of the catering mechanism has increased belief in the potential benefit of this undertaking

for mankind; and that, if for any reason a decision to construct an interoceanic canal is delayed beyond the next several years, nuclear excavation technology might be available for canal construction.

It is clear that the technical feasibility of using nuclear explosives for Isthmian canal construction has not been established and that any conclusion as to its technical feasibility in the future for this purpose would be a speculative judgment of the potential of nuclear excavation for the most sophisticated task that could be asked of it. It is equally clear that the United States could not propose such excavation until the reliability of the technology for such an application has been proved unconditionally.

Although mindful of, and in essential agreement with, the AEC's prognosis of eventual availability of a nuclear excavation technology, the Canal Commission believes that many experiments will be required in combination with practical applications in smaller projects before the necessary degree of confidence can be assured. Although there is a considerable body of scientific and engineering opinion that the technology has already been sufficiently developed for application to projects of moderate size, such as harbors and highway cuts, it is the view of this Commission that its perfection for use in canal excavation on Routes 17 or 25 is many years away.

Acceptability of Nuclear Canal Excavation

The political constraints upon the use of nuclear explosives for canal excavation were recognized at the time the Commission's investigation was authorized by the Congress. It was reasoned in the authorization hearings, however, that establishment of the technical feasibility of nuclear canal excavation through experiments and practical applications of this technology within the United States would ease removal of treaty constraints and other political obstacles to its use for canal excavation. This reasoning was valid in 1964 and remains so today, but neither technical nor political developments have proceeded at the expected pace. Consequently, the international and local obstacles to nuclear canal excavation are essentially unchanged from 1964. Although there have been encouraging developments in international treaties bearing upon nuclear excavation, the Limited Test Ban Treaty constraints remain in effect, and the Commission's studies indicate that prospective host-country opposition to nuclear canal excavation is probably as great if not greater than estimated in 1964.

The Limited Test Ban Treaty enjoins its signatories from conducting any nuclear explosion which causes radioactive debris to be present outside the territorial limits of the state under whose jurisdiction or control such explosion is conducted. The United States recognizes, because there seems to be no possibility of excavating an Isthmian canal with nuclear explosives without transport of some radioactive material across territorial boundaries, that this provision could prohibit nuclear excavation of a sea-level canal. It was also recognized by the United States and other signatories, including all canal-site countries, that nuclear excavation for peaceful purposes could later become practicable and mutually acceptable. Consequently, the Treaty was drafted to provide simple amendment procedures, requiring only the concurrence of the United States, Great Britain, Russia, and a simple majority of the parties to the Treaty.

Two other treaties bearing upon control of nuclear explosions have come into force subsequent to the ratification of the Limited Test Ban Treaty. Both contain specific provisions designed to facilitate the use of nuclear explosions for peaceful purposes, including excavation, when the technology is developed and when mutually acceptable procedures are established. In the Treaty of Tlatelaco (the Latin American Nuclear Free Zone Treaty) fifteen Central and South American countries, including all Isthmian canal-site

countries, agreed to exclude nuclear weapons from their territories but specified conditions for mutual cooperation in the employment of nuclear explosives for peaceful purposes.

The international agreement most encouraging for the future development of nuclear excavation technology is the Nuclear Non-Proliferation Treaty now ratified by the three principals and a majority of the signatories of the Limited Test Ban Treaty. Article V of this Treaty provides that:

> Each Party to the Treaty undertakes to take appropriate measures to ensure that, in accordance with this Treaty, under appropriate international observation and through appropriate international procedures, potential benefits from any peaceful applications of nuclear explosions will be made available to non-nuclear-weapon States Party to the Treaty on a nondiscriminatory basis and that the charge to such Parties for the explosive devices used will be as low as possible and exclude any charge for research and development. Non-nuclear-weapon States Party to the Treaty shall be able to obtain such benefits, pursuant to a special international agreement or agreements, through an appropriate international body with adequate representation of non-nuclear-weapon States. Negotiations on this subject shall commence as soon as possible after the Treaty enters into force. Non-nuclear-weapon States Party to the Treaty so desiring may also obtain such benefits pursuant to bilateral agreements.

The obligation assumed by the nuclear powers under Article V creates an environment conducive to gaining international agreement upon modification or interpretation of the Limited Test Ban Treaty to permit nuclear excavation projects. Discussions at the technical level between United States and Russian representatives in 1969 and 1970 indicated that Russia has great interest in the nuclear excavation technology and may be considerably ahead of the United States in its development. These conferences produced joint statements in favor of continued discussion of the technical aspects of peaceful nuclear excavation technology; specific arrangements for dealing with the constraints of the Limited Test Ban Treaty remain to be initiated.

Opposition to release of additional radioactive material in the world environment probably would not be stilled by negotiation of a Limited Test Ban Treaty modification authorizing peaceful nuclear explosive excavations. Many people throughout the world, including some scientists, may remain convinced that the levels of radioactivity expected to be released to the environment would not be acceptable.

The Commission's Study of Foreign Policy Considerations (Annex I) concluded that within the canal-site countires, fear of the effects of nuclear explosions and fear of economic dislocations could create major obstacles to nuclear canal excavation. The problems differ in magnitude among countries, but none appears easily overcome.

It was found that more than a half-million people would have to be evacuated from areas of Nicaragua and Costa Rica to permit nuclear excavation of Route 8. The Commission then concluded that nuclear excavation of this route should be given no further consideration.

The evacuation requirements for Route 17 are formidable at this time and will grow more so with the passage of time as the Darien area develops economically. The evacuation area includes the homelands of Choco and Cuna Indian tribes with primitive cultural attachments to their lands that could not be broken easily. A larger area extending to Panama City on the west and Colombia on the east would be subject to possible ground motion and airblast damage. The potential damages to masonry structures and window

panes outside the evacuation area would not be costly to repair, but the inconvenience to thousands of inhabitants could be considerable. An additional major obstacle for Route 17 construction is the prospect of economic losses and dislocations in moving canal operations away from Panama's metropolitan centers (See Chapter VII). These economic disturbances, the imagined dangers of nuclear excavation, and the objections to evacuation of inhabitants from the Route 17 area could cause widespread Panamanian opposition to a Route 17 canal.

The employment of nuclear explosives in the Continental Divide area of Route 25 in Colombia would involve lesser problems of acceptability than would nuclear excavation in Panama. The land area of evacuation would be only one-half as large. Although many of the inhabitants of this area are Choco Indians whose removal would present problems similar to those expected in Panama, the total evacuation requirement would involve only one-quarter as many people. The required precautions against airblast and seismic shock would affect an area of nearly the same magnitude as for Route 17.

The problems of public acceptance of nuclear canal excavation probably could be solved through diplomacy, public education, and compensating payments. However, the political and financial costs to the United States in obtaining such acceptance could offset any potential saving in construction costs and gains in intangible benefits. Obviously, a wide, deep channel constructed at low cost by nuclear excavation would have specific advantages in military security and ship-size capacity in comparison with a conventionally excavated canal. However, compensation costs unique to the dislocations and damages associated with nuclear excavation, costs that not only would be incurred prior to and during construction but also might be incurred for many years thereafter, would remain unknown quantities until actually negotiated. Although pioneering in such a massive nuclear excavation project would certainly add to the scientific and engineering stature of the United States, proceeding with nuclear construction against extensive minority opposition would detract from that prestige.

Summary

In the judgment of the Commission, the current prospects of nuclear canal excavation are:

- At the present state of development of the nuclear excavation technology the feasibility of its use in excavation of an Isthmian sea-level canal has not been established. It is possible that the technology can be perfected to where such an application is technically feasible, but many more nuclear excavation experiments are needed. Technical, political, and budgetary constraints probably will continue to slow development of the technology.
- The outlook on balance favors eventual attainment of international acceptance of practical applications of the nuclear excavation technology, but the time needed to establish the necessary arrangements under the Limited Test Ban Treaty is unpredictable.
- It is not possible at this time to determine whether a nuclear excavated canal would be acceptable to Panama. The use of nuclear excavation on Route 17 may be precluded by economic developments in the vicinity.
- It is unlikely that nuclear excavation will become technically feasible on enough of Route 17 to permit substantial cost savings in comparison with the cost of all-conventional sea-level canal construction elsewhere in Panama.

- It is probable that the technical feasibility and cost advantages of the use of nuclear explosives for excavation of portions of Route 25 in Colombia could be established by an adequate program of experiments. The future acceptability of such a canal in Colombia cannot now be determined.

CHAPTER V

GENERAL CRITERIA

Evaluation of the costs of the several routes considered for construction of a sea-level canal required that the basic criteria of design and construction be the same for each route. These criteria include: the maximum size of ship to be accommodated; the maximum acceptable velocity of tidal currents; the size and shape of the navigation prism; the side slopes of the excavation above the water surface required for stability; and the methods of construction.

Size of Ships

Ships up to only 65,000 deadweight tons* can be passed through the locks of the Panama Canal and very few ports in the United States can accommodate larger ships. The world fleet, however, now includes many tankers and dry bulk carriers twice this size or bigger. The Shipping Study Report (Annex IV) predicts that the proportion of such ships in the world fleet during the period from 2000 to 2040 would probably be as shown in Table 11.

The Commission concluded from these data that the demands of future world commerce would adequately be met by providing for the transit of ships of 150,000 DWT under all normal conditions of operation of a sea-level canal between the Atlantic and Pacific Oceans.

TABLE 11

FORECAST PROPORTIONS OF SUPER SHIPS IN THE WORLD FLEET

		Size Equaled or Exceeded – DWT		
Class	**Year**	**100,000**	**150,000**	**200,000**
Freighters	2000	None	None	None
	2020	None	None	None
	2040	None	None	None
Bulkers	2000	3%	2%	1%
	2020	6%	3%	2%
	2040	10%	3%	2%
Tankers	2000	16%	5%	2%
	2020	28%	10%	3%
	2040	44%	18%	8%

*See footnote on page 25.

Transit Capacities

Traffic through the Panama Canal has built up to more than 15,000 ships per year. It is estimated by the Panama Canal Company that the future limit, without construction of additional locks, will be 26,800 transits per year.

Recent trends indicate that the average amount of cargo per ship will increase more rapidly in coming years than will the number of transits because of the increasing numbers of large bulk carriers and tankers appearing in the canal ship mix. This divergence of the growth rates of cargo tonnages and ship transits would undoubtedly become greater with the opening of a sea-level canal that could accommodate ships of 150,000 DWT or greater.

The Commission concluded from the studies described in Annex IV that the demands of world commerce would be well satisfied by providing for 35,000 transits per year initially by means that would not preclude later expansion to at least double or even treble that number.

Navigation and Tidal Currents

Safety of navigation of a sea-level canal will be a controlling factor. The existence of currents will impose few restraints on the passage of small ships but very large ships might be unmanageable in an unrestricted canal under adverse tidal conditions.

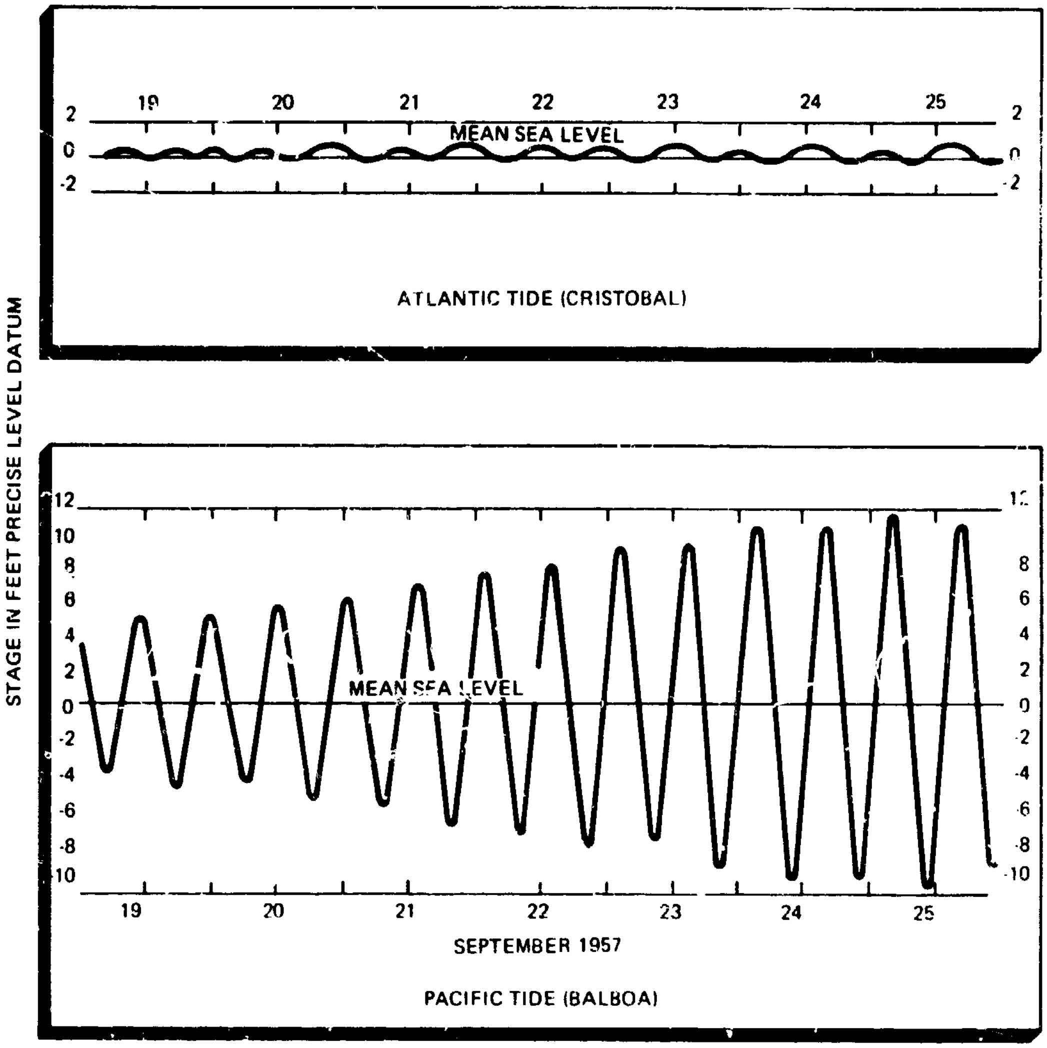
Tidal fluctuations in the Atlantic along the Isthmus of Panama are small and somewhat erratic. The tides on the Pacific side, on the other hand, are large and quite regular. The resulting variations in level for a typical period are shown on Figure 17. The mean level of the Pacific at Balboa averages eight inches higher than in the Atlantic at Cristobal.

If an unrestricted sea-level canal were built to connect these oceans, there would thus be oscillating flow with net movements of water from the Pacific to the Atlantic. The currents so produced would depend on the difference in levels at the time, on the length of the canal, and on the size and shape of the navigation prism. The magnitude and direction of such currents at all points along the several canals considered are set forth in Annex V together with a description of the mathematical methods used to compute them. It was found, for example, that on Route 10 the velocities of flow would be greatest at the Atlantic entrance and would reach 5.1 knots on a few days each year and 3.7 knots under average tidal conditions. Velocities of flow in a nuclear excavated canal would be substantially greater, because of its greater cross-sectional area.

The Commission conducted extensive studies to determine the controllability of ships, with consideration of the effects of currents, in a navigation prism of restricted width and depth; these included a review of operating conditions in existing canals and restricted waterways, a comprehensive mathematical analysis, and a series of tests of large-scale ship models in a confined channel.

These studies indicate that:

1. The desirable speed of ships with respect to the land is 7 knots, equivelant to 8.05 statute miles per hour.
2. The speed of ships with respect to the water should not be less than 4 knots for ships smaller than 50,000 DWT nor less than 5 knots for larger ships.
3. At least one powerful tug should be provided for control of each ship long enough to cause blockage of the channel should the forward speed of this ship become less than the velocity of the following current.
4. Powerful tugs should also be provided for assistance in stopping and for additional control of all large ships and of small ships of limited maneuverability.



SEVEN DAY TIDE RECORD

FIGURE 17

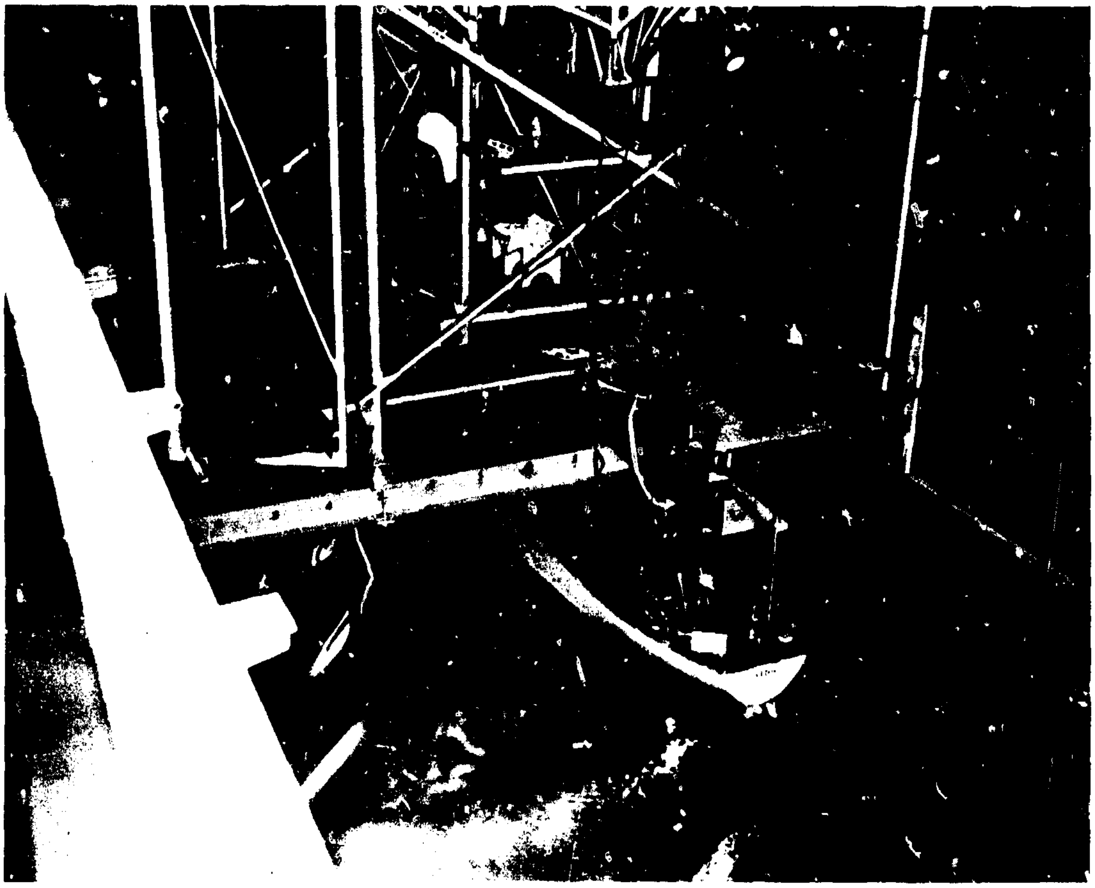
Tug assistance is required for all large ships in the present canal and is expected to be similarly required in a sea-level canal.

FIGURE 18

Tidal Checks

The uncertainty of safety of navigation under all tidal conditions led to consideration of a new concept: the installation of a tidal control structure at each end of a long restricted reach to limit the velocities of flow in a sea-level canal. It is contemplated that one structure and gate would be located close to the Pacific entrance and another 24 to 25 miles north thereof. The check gates would be moved alternately into position across or out of the channel at intervals of 6.2 hours or some multiple thereof when the Pacific is at the same level as the Atlantic. Under these conditions, the maximum velocity of flow would be approximately 2 knots at the Pacific entrance and less elsewhere. It is also contemplated that structures for gates would be built close to the Atlantic entrance where, if a gate were installed and employed alternately with the Pacific gate, the maximum velocity could be held to approximately 3 knots.

The contemplated tidal controls do not resemble the tidal lock and by-pass arrangement proposed in the 1947 Study. The gates would not function as locks; no lifting of ships would be involved, and no ship would have to stop in transit. They would be operated as a pair; one would be rolled or floated into position across the channel at an appropriate time;



Scale model of a 250,000 DWT tanker undergoing tests in the Naval Ship Research and Development Center to determine the controllability of large ships in a sea-level canal.

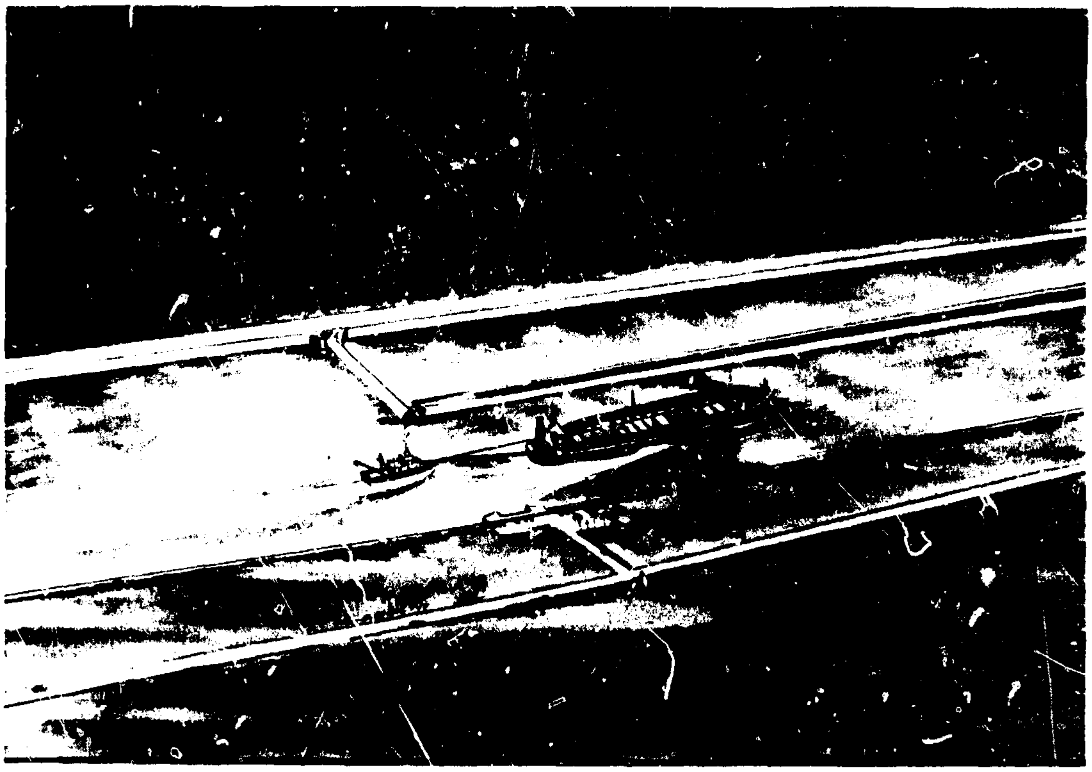
FIGURE 19

the other would be moved simultaneously back out of the way of oncoming ships. Their position would then be reversed 6.2 or 12.4 hours later.

These tidal check gates would not have significant military vulnerability. Even if one or both should be rendered inoperational by sabotage or military attack, they could easily be removed from the channel. The higher tidal currents then encountered would not materially impede the movement of warships and military cargo vessels through the canal. Figure 20 is an artist's sketch of a tidal check structure at one end of the bypass in a sea-level canal.

The use of tidal checks at the ends of a one-way channel would require that all ships be transited in convoys, scheduled to arrive at a check just after it is opened so that no ship would have to stop or materially change its speed. These times will not be random; they can be predicted accurately many months in advance after a few observations are made to measure the lag in time with respect to the Pacific tides.

The length of each convoy will necessarily be limited by the distance between the tidal checks. It has been found, as described in Annex V, that 4 ship lengths from bow to bow would be a satisfactory average spacing. This distance between ships plus an allowance of at least one mile of clear space ahead of the first ship in a convoy and of one-half mile behind the last ship gives the following for certain critical locations of checks:



Artist's Sketch of a Tidal Check at the Entrance to a Bypass Channel

FIGURE 20

TABLE 12

MAXIMUM NUMBERS OF SHIPS IN CONVOYS
WITH TIDAL CHECKS IN USE

DISTANCE IN MILES BETWEEN CHECKS	NUMBER OF SHIPS IN CONVOY
14	24
25	46
36	68

The shortest distance shown in this tabulation is that between the ends of a bypass, consisting of 2 separate one-way channels, that could be constructed to augment the transit capacity of a single-lane channel on Route 10. The largest distance is that between the Pacific and Atlantic entrances of a canal on either Route 10 or Route 14. The intermediate distance is the longest that would permit the use of an 18.6 hour convoy cycle; it also would put a tidal check at the Atlantic end of a future bypass on Route 10.

The Commission elected to include in the designs structures for support of tidal gates at or near the ends of each sea-level canal under consideration except Route 25, at each end of

the potential bypass on Route 10, and at a point 24 miles north of the Pacific entrance of Route 14.

Figure 21 schematically portrays the location and operation of the tidal checks in the single lane configuration. Figure 22 similarly shows the operation of the bypass configuration.

Cross Section of Navigation Prism

The Commission recognized early in its studies that the transit capacity of a single-lane channel on all but the very long routes would meet all probable demands for many years and that this capacity could most economically be augmented by the addition of a bypass. The Commission also recognized that the cost of construction would be increased greatly by providing for two-way traffic, because the width of a two-way channel should be more than double the width of a single-lane canal.

It was developed from the comprehensive studies described in Annex V that any of the following combinations of ship speed, channel width, and channel depth would provide equal navigability for 150,000 DWT ships:

TABLE 13

SINGLE-LANE CHANNEL DIMENSIONS FOR SAFE NAVIGATION OF 150,000 DWT SHIPS

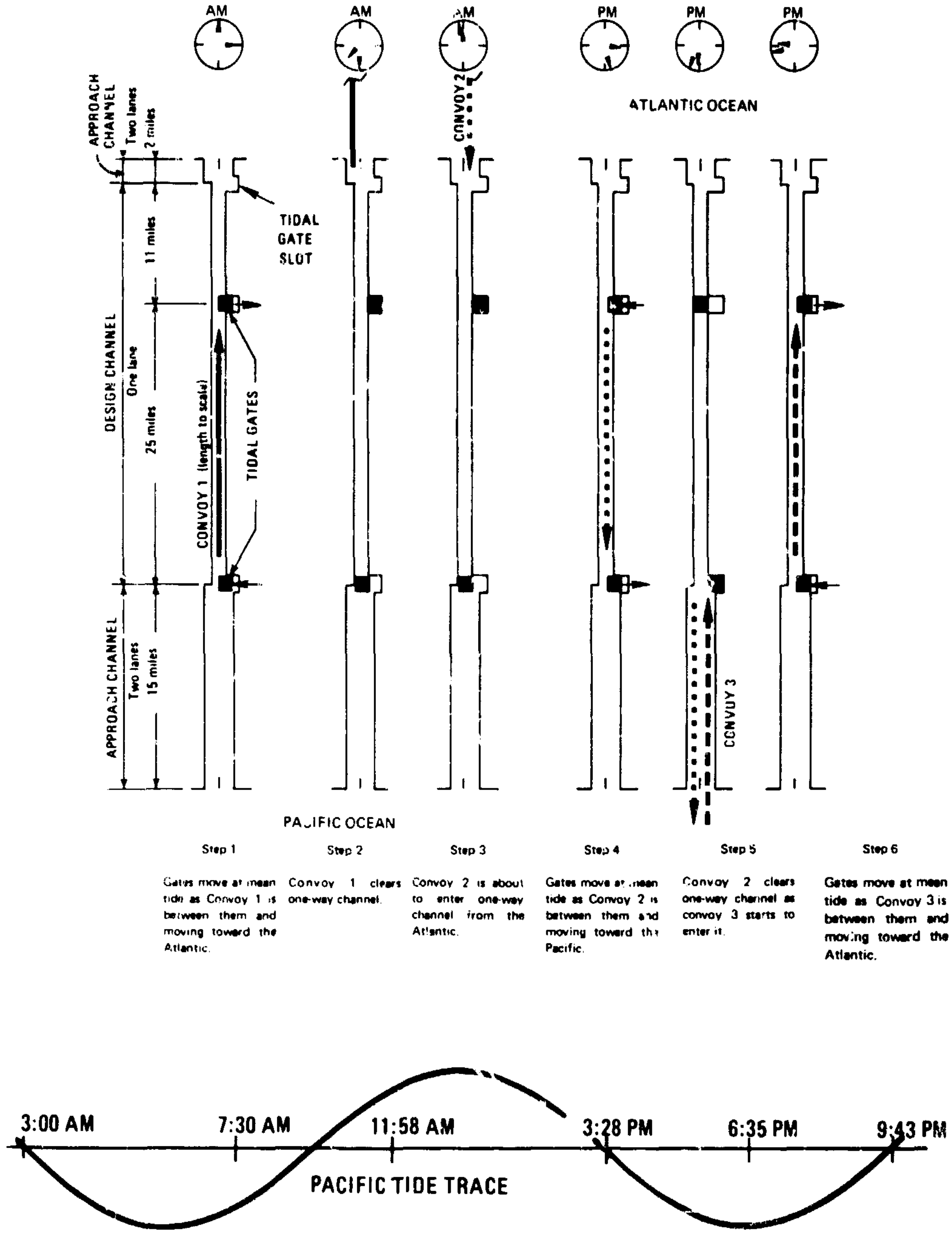
Speed in Water	Bottom Width Feet	Water Depth Feet
9 Knots	500	72
	5[illegible]0	60
11 Knots	550	85
	600	77
	650	65

The Commission recognized that the 9-knot ship speed in the water was for the condition of 2-knots current with tidal checks in service and that the 11-knot ship speed was based on passage against a 4-knot current. It accepted, however, the recommendation of its Engineering Agent that this higher velocity be used for cost estimating purposes because it may be found practicable over the years to operate in currents of this velocity, and because it would permit passage of 250,000 DWT ships under controlled conditions.

The Commission, therefore, elected to use for all conventionally excavated channels a single-lane navigation prism, having a bottom width of 550 feet, a center depth of 85 feet, and a depth at the sides of 75 feet.

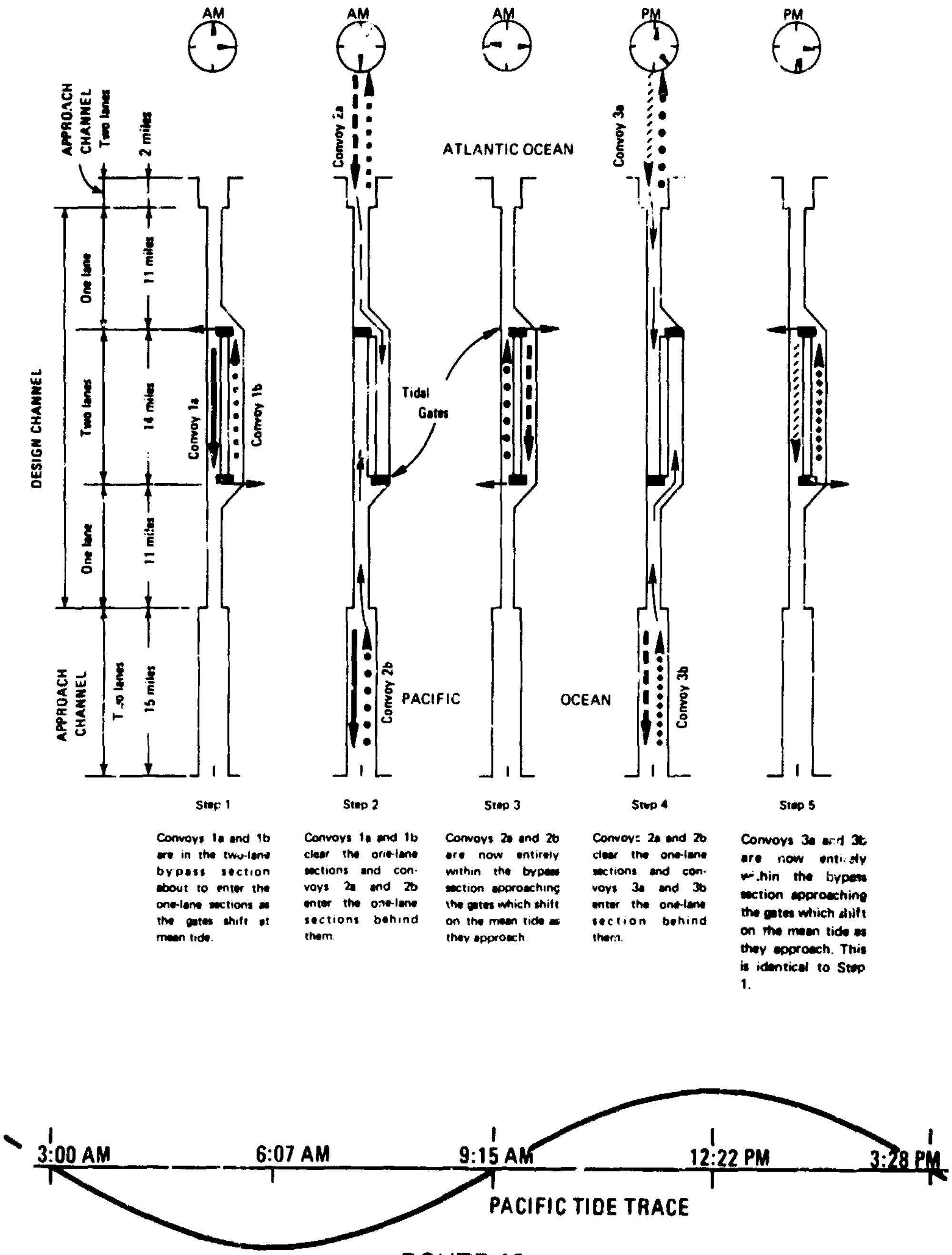
Side Slopes of Excavation

At the time the Panama Canal was built there was little knowledge of soil and rock mechanics and much steeper slide slopes were used than would now be customary. Most of



ROUTE 10
SINGLE-LANE
PLAN OF OPERATION
2-KNOT ALLOWABLE CURRENT
18.6-HOUR CYCLE

FIGURE 21



ROUTE 10
BYPASS
PLAN OF OPERATION
2-KNOT ALLOWABLE CURRENT
6.2 HOUR CYCLE

FIGURE 22

the slides along the Panama Canal have stemmed from this cause.

The Technical Associates of the Commission, after review of geologic and other conditions along the existing canal and the several routes for a sea-level canal, recommended that the slope criteria given in Table 14 be used in calculations of the quantities of material to be excavated.

The proper side slopes for deep excavation in hard rock and soft rocks were also investigated by the Engineering Agent. as described in Annex V. The findings of this study were consistent with the recommendations of the Technical Associates. The Commission accepted, for purposes of evaluating the costs of construction of a sea-level canal on each of the several routes, the recommended slope criteria.

Construction Methods

The potential of nuclear excavation is discussed in a separate chapter; hence, this review of construction methods is limited to conventional procedures.

Excavation will be the largest item of cost of a sea-level canal on any of the routes considered, because of the tremendous volumes of material to be removed. The unit costs (dollars per cubic yard) will vary widely depending on the nature of the materials and whether or not the channel must be excavated below water. The unit cost of excavation of hard rock will naturally be more than that of soft rock. The unit cost of removal of any material will be less if the work can be done above water than if it has to be dredged, except for unconsolidated deposits at moderate depths.

The Commission recognized that, in the years before actual construction of a sea-level canal would be started, there probably will be major changes in methods and improvements in equipment, but it directed that all estimates of cost be based on proved methods of construction and on only foreseeable improvements of equipment now available. Four general methods of excavation and their application to the different routes are described in Annex V. These methods are:

1. Power shovels and truck haul disposal for isolated portions of the work and to remove the tops of hills.
2. Power shovels and railroad haul disposal for the major portion of all excavation above water.
3. Barge mounted shovels or draglines or bucket dredges and barge haul disposal of material excavated below water.
4. Hydraulic dredges and pipeline disposal of unconsolidated sediments below water.

TABLE 14

RECOMMENDED SIDE SLOPES OF EXCAVATIONS FOR DIFFERENT MATERIALS AND HEIGHTS

Nature of Material	Side Slopes of Cut Horizontal ÷ Vertical				
High Quality Rock	0.375 Overall Including Construction Benches				
Intermediate Quality Rock	0.625 Overall Including Construction Benches				
Low Quality Rock Such as Clay Shale	Height of Cut in Feet				
	100	200	300	400	500
Condition A	1.0	4.1	6.0	7.5	8.6
Condition B	1.0	5.3	7.8	9.5	10.7
Condition C	1.0	6.4	9.2	11.4	13.0

Condition A: For locations where the canal would be remote from the existing canal. (The existing canal would be available for use during a proving period.)

Condition B: For locations where the canal would be separate from the existing canal but in close proximity. (Excavation would be performed in the dry and gradual drainage would be possible during construction. An observational period would be available prior to the canal becoming operational.)

Condition C: Locations where the canal would be adjacent to the existing canal in an area with a history of slides. (The area would have undergone long-term creep, and the slopes would be subject to rapid drawdown. The maintenance of traffic on the Panama Canal during construction is considered.)

Earth slide blocking the Panama Canal in the Gaillard Cut, October 1915

FIGURE 23

CHAPTER VI

ENVIRONMENTAL CONSIDERATIONS

Construction of a sea-level Isthmian canal would impact on the land and ocean environments in several ways. The physical effects can be estimated with some confidence for both. The total effects upon land ecology can also be estimated with confidence, but the effects upon ocean life are now uncertain because of the dearth of knowledge of the regional ocean ecology.

The Land Environment

Canal excavation on any route would require clearing a right-of-way across the Isthmus and disposal of great volumes of spoil on land and off-shore. These effects from conventional excavation would extend a few thousand yards from the canal routes; the spoil areas and destruction of forested areas incidental to nuclear excavation would be more extensive. The excavation and spoil disposal plans for each conventionally excavated route provide for containment of most spoil in areas where runoff would be least harmful and where the fill would be most useful.

Stream courses would be altered where they intersect a canal on any route. Construction of a sea-level canal on either Route 10 or Route 14 would divide Gatun Lake; in the case of Route 10 there would be no material change in total area, but on Route 14 the remaining surface area would be about 62 square miles as compared to the present area of 165 square miles.

The Panama Canal is already a barrier to faunal migration along the Isthmus. Any new canal would be an added barrier.

Detailed estimates of the areas that would be affected on each route are contained in Annex V, Study of Engineering Feasibility, together with specific estimates of potential environmental effects. It can be concluded from these estimates that all permanent effects on land areas would be limited to the immediate vicinity of the canal routes and would result in no harmful ecological changes of significant magnitude. For the conventionally excavated routes, the potential changes of the land environment and the freshwater ecology appear to be less than those that were created by construction of the existing canal which required the creation of Gatun Lake.

Medical experience in Central America and medico-ecologic studies performed for the Commission have demonstrated the need for stringent and continuing preventive-medicine measures and a responsive medical support program. Insect and rodent control, waste disposal, and health education would be particularly important. Immunization would be directed primarily against yellow fever, smallpox, typhoid fever, and tetanus. A special effort would have to be made to control malaria and other parasitic diseases, enteric diseases, and other tropical ailments. The present conditions in the Canal Zone demonstrate that a healthy environment can be achieved with a well planned and executed medical program.

The Ocean Environment

Physical Effects

The permanent physical changes, e.g., temperature, currents, and salinity, to the ocean environment as a result of opening a sea-level Isthmian canal would be small and limited to areas adjacent to the canal entrances. The water level on the Pacific side, twice each day, rises from 5 to 11 feet above and falls 4 to 10 feet below that on the Atlantic side. A sea-level canal without tidal control structures would thus have strong currents that would change direction twice each day with the rise and fall of the tides. While no single tidal phase would endure long enough to cause a complete flow-through of water from one ocean to the other, there would be a gradual net transport of water from the Pacific to the Atlantic because of the slightly higher mean sea level of the Pacific. The transported water, however, would be drawn from the upper levels of Panama Bay where it is already within a few degrees of the water temperature on the Atlantic side. It would tend to become warmer as it moved back and forth in the canal until it ultimately emerged at the Atlantic end. The predicted effects on the receiving ocean's temperatures or currents are insignificant.

Spoil disposal and breakwater construction would considerably alter the existing shore configurations and fill in large offshore areas. However, similar operations affected almost as large an area in the construction of the present canal. Colon on the Caribbean side and Fort Amador on the Pacific side were once ocean areas. No harmful environmental effects have been identified with these large landfills.

Underwater excavation on Route 14 would have a very substantial effect on the water in Gatun Lake; there would be some effect also caused by underwater excavation in the approaches to any canal. Excavation in the dry, however, which would represent most of the work on Route 10, could have only a nominal effect upon ocean areas near the entrances. It is unlikely that sediment would be carried in canal flows, predominantly from the Pacific to the Atlantic, in excess of the sediments that would reach the oceans naturally.

Biotic Interchange

An unobstructed sea-level canal across the Isthmus would allow relatively easy passage of marine organisms. Certain forms of marine life now pass through the Panama Canal even though Gatun Lake provides a highly effective biotic barrier. Barnacles and other immobile organisms are carried through on the hulls of ships, and a variety of small plants and animals is carried in ballast water from one ocean to the other. Transfers of marine life by these means have been taking place continuously for more than 50 years. No harmful results have yet been identified in either ocean as resulting from them. However, linking the oceans with an unobstructed salt water channel would greatly facilitate the movement of these and other organisms.

Taxonomic studies indicate that the Atlantic and Pacific Ocean species along the Isthmus are closely related, even though few are identical. The similarity results from the linking of the Atlantic and Pacific Oceans until recent geologic time, perhaps 3 million years ago. Concern has been expressed about the potentially undesirable biologic consequences when such closely related species are allowed to intermingle and about the ecological consequences of the movement of marine organisms generally. Marine biologists are not in agreement on this subject; their predictions range from disaster to possible

beneficial results.

Because of the great divergence of views on the ecological consequences of a sea-level canal, the Commission had a study made of the potential effects. This study, a limited one because of time and fund constraints, was accomplished by the Battelle Memorial Institute (BMI) in association with the Institute of Marine Sciences of the University of Miami. The ocean populations on both sides of the Isthmus were studied, giving special attention to the fish and crustaceans that are important to commercial and sport fishermen. The potential transport of water, chemicals, sediment, and planktonic organisms between the oceans was mathematically modeled and the resultant effects postulated. The BMI findings are summarized as follows:

> On the basis of the limited ecological information currently available we were unable to predict the specific ecological consequences of marine mixing via a sea-level canal. Preliminary modeling studies indicate that the net flow of water would be from the Pacific to the Atlantic. This would result in minor environmental changes near the ends of the canal and near the shore to the east of the Atlantic terminus. Passive migration of planktonic organisms would occur almost entirely in the same direction. Active migration of nekton could occur in either direction, but environmental conditions in the canal would favor migration from the Pacific to the Atlantic. We have found no firm evidence to support the prediction of massive migrations from one ocean to another followed by widespread competition and extinction of thousands of species.
>
> Evidence currently available appears to indicate a variety of barriers to migration of species from one ocean to another and/or the subsequent establishment of successful breeding colonies in the latter. Environmental conditions in the canal would constitute barriers to the migration of both plankton and nekton, and the effectiveness of these barriers could be enhanced by engineering manipulations of freshwater inputs to the canal and other artifical means. The marine habitats and biotic communities at the opposite ends of most proposed sea-level canal routes are strikingly different. Where similar habitats do occur on both sides of the Isthmus, they are already occupied by taxonomically similar or ecologically analogous species. These differences in environmental conditions on the two sides of the Isthmus and the prior occupancy of similar niches by related or analogous species would constitute significant deterrents to the establishment and ecological success of those species which may manage to get through the canal.
>
> It is highly improbable that blue-water species like the sea snake and the crown-of-thorns starfish could get through the canal except under the most unusual circumstances. On the other hand, we can be fairly certain that some Pacific species could pass through the canal and could become locally established in the Pacific waters of the Atlantic. It is also improbable that these species would be able to survive in the Atlantic outside the region of environmental modification due to water flow through the canal. The Pacific species most likely to become established along the Caribbean shore are those of estuarine and other shallow-water habitats, the very habitats that have been least thoroughly studied.
>
> To improve the precision and reliability of these and similar ecological predictions would require additional information and quantitative data which

could be provided only by a comprehensive program of field, laboratory, and theoretical (modeling) studies. Extensive taxonomic surveys would be required to improve our knowledge of the biota of the Tropical Western Caribbean and Tropical Eastern Pacific. Except for a few economically important species, ecological life history data are virtually non-existent. Basic biological studies would be required to obtain such information. The geographical extent and physiochemical characteristics of the marine habitats on the two sides of the Isthmus are imperfectly known from a few cursory surveys. The species composition and functional-ecological structure of the biotic communities that characterize these habitats are imperfectly known and inadequately understood. The parameters required to predict the flow of water and plankton through the canal have not been adequately measured. The processes of migration, establishment, and competition have been but little studied and are not well understood. To remove these deficiencies in our knowledge would require a comprehensive, long-term program of well-coordinated physical oceanography, marine ecology, and basic marine biology studies.

The risk of adverse ecological consequences stemming from construction and operation of a sea-level Isthmian canal appears to be acceptable. Since it is not possible to determine the specific ecological effects without extensive studies before, during, and after construction, the Commission requested the National Academy of Sciences (NAS) to recommend a program of long-term studies to be undertaken if the decision is made to build a sea-level canal. The complete NAS report and recommendations, together with the report of the BMI study, are included in Appendix 16 to Annex V, Study of Engineering Feasibility.

Should future research indicate the need for a biotic barrier in addition to tidal gates it would be possible to install a temperature or salinity barrier. No such barrier was included in the designs, because the need for anything in addition to tidal gates has not been established. A thermal barrier created by discharge of hot condenser water from a power plant into the canal between the tidal gates would be feasible, although the costs would be high. Delivery of fresh water from Gatun Lake into a Route 10 or Route 14 sea-level canal between the tidal gates would be practicable, but the available supply of water is limited. Continuous operation of tidal gates on either Route 10 or Route 14 would accommodate all potential traffic past the year 2000, by which time the consequences of increased migration of biota through the canal should have been determined.

Combined Effects

The environmental impact statements required by Section 102 of the National Environmental Policy Act of 1969 (Public Law 91-190) are included in Annex V, Study of Engineering Feasibility. These statements cover not only the effect of mixing the oceans but other environmental changes which could be expected as a result of constructing a sea-level canal.

CHAPTER VII

ANALYSIS OF ALTERNATIVES

The choice of a feasible sea-level canal excavated by conventional means is limited to Routes 10 and 14. In the analyses which follow these two alternatives are examined in detail.

The route technically most promising for construction using nuclear explosives is Route 25 in Colombia; this is analyzed for possible future consideration, should the feasibility of nuclear excavation eventually be established. A limited analysis of Route 17 is also included, although its selection is considered unlikely.

As a basis for evaluating the incremental costs and benefits of a sea-level canal, an analysis of augmentation of the existing lock canal is also provided.

Each of these alternatives is evaluated on the bases of its engineering feasibility, cost, capacity, expandability, political acceptability, and its defense aspects.

Routes 5, 8 and 23 are analyzed only briefly, inasmuch as they are clearly less desirable than other routes.

A brief description of the capabilities of the present lock canal is provided as a point of departure.

The Panama Canal

The existing lock canal (Route 15) consists of short sea-level approaches to an elevated midsection formed by Gatun Lake, which is regulated between elevations 82 and 87 feet above sea level (Figure 24). The Gatun Locks on the Atlantic side consist of parallel twin locks of three equal lifts. On the Pacific side there are two lock structures – a double lift at Miraflores which raises transiting vessels to an intermediate pool called Miraflores Lake, and a single lift at Pedro Miguel raising the vessels to the level of Gatun Lake. All lock chambers are 1,000 feet long, 110 feet wide, and at least 41 feet deep. The lock dimensions limit transits to ships with lengths of less than 1,000 feet, beams of not more than 106 feet, and drafts of less than 40 feet (approximately 65,000 DWT). Its annual capacity is now limited by the available water supply to approximately 18,000 transits per year. The ultimate capacity of the existing locks, upon completion of the long-term improvement program of the Panama Canal Company, is estimated to be 26,800 annual transits. This program. involving costs of approximately $100 million, includes provisions for pumping sea water into Gatun Lake or recirculating lockage water.

Alternatives Eliminated from Further Consideration

Routes 5, 8, 17, and 23 were found to have disadvantages of sufficient magnitude to eliminate them from consideration as alternatives to other routes. The reasons for doing so are briefly summarized. Details are in the Annexes to this report.

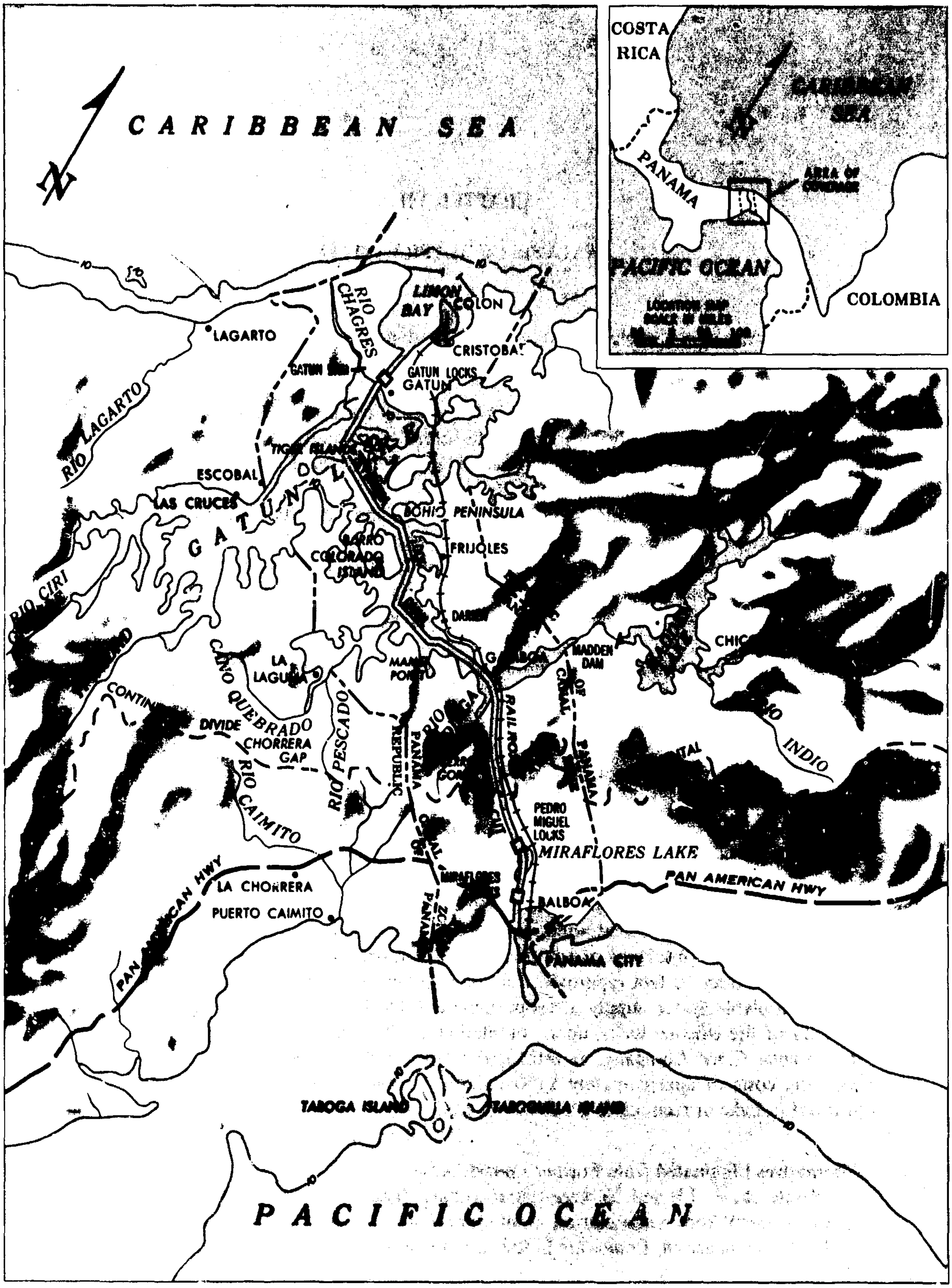
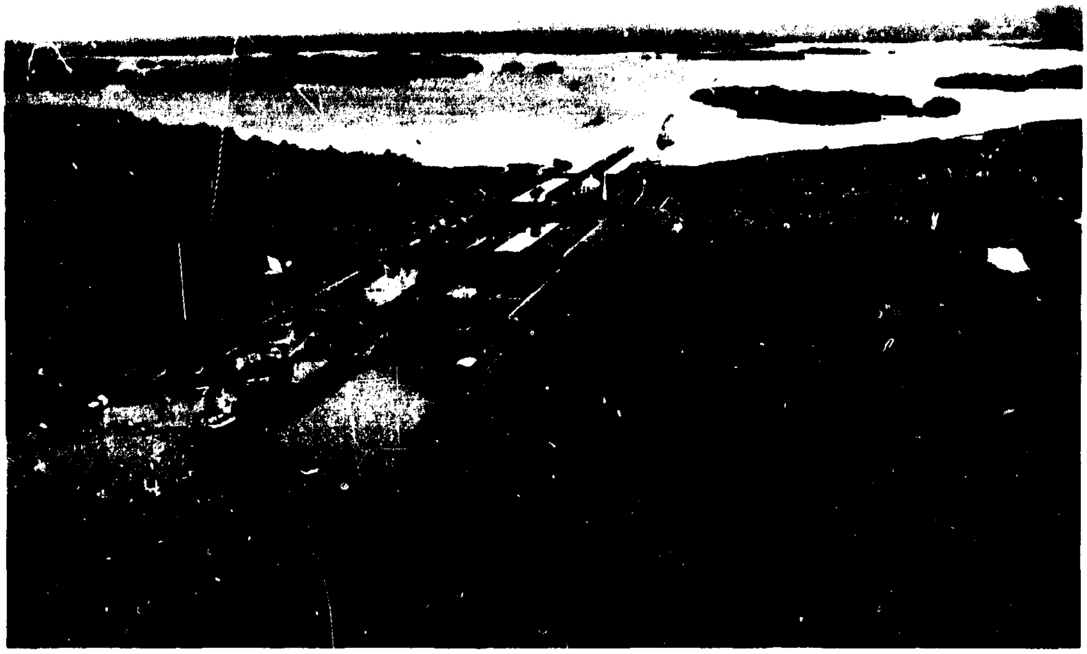


FIGURE 24

THE CANAL ZONE

SCALE IN MILES
5 0 5 10

DEPTH IN FATHOMS

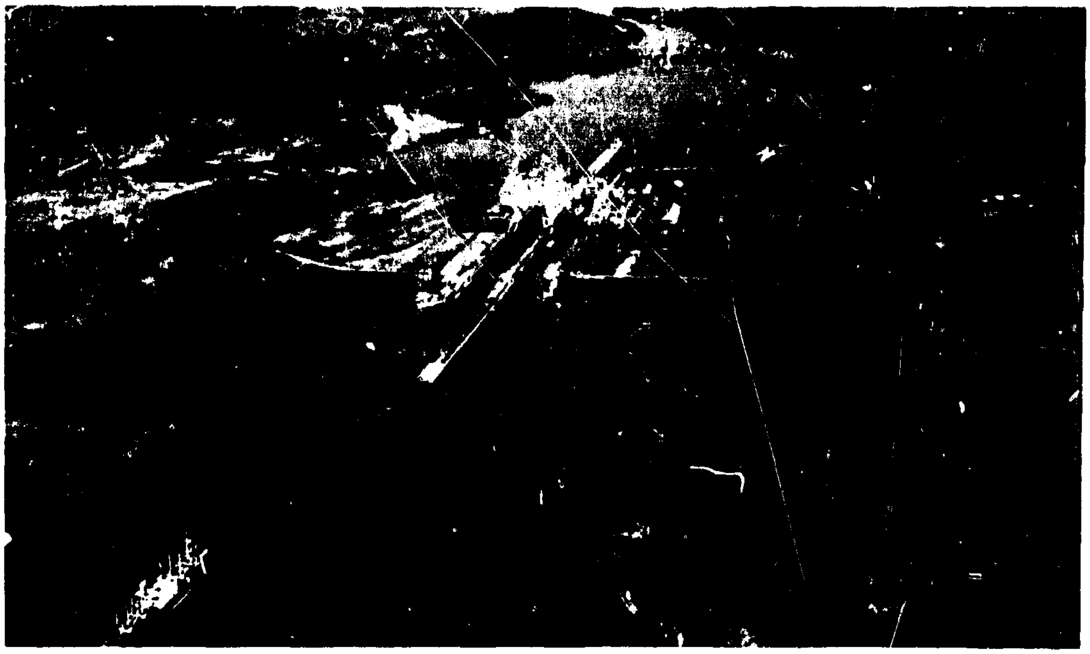


Gatun Locks at the Caribbean end of the Panama Canal

FIGURE 25

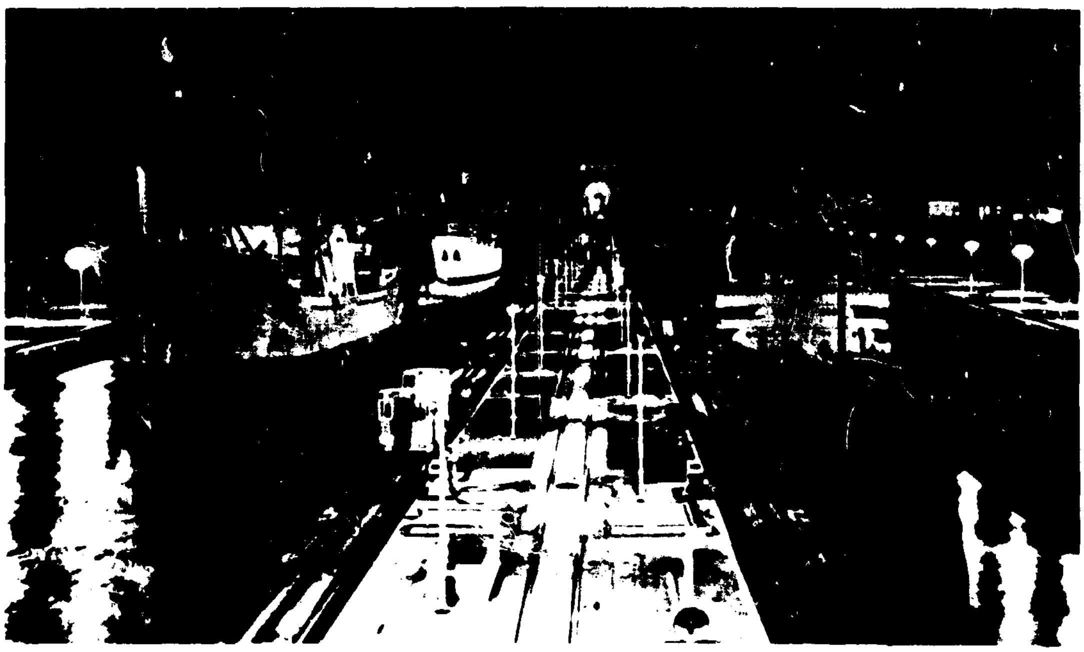
Widening the Panama Canal channel from 300 feet to 500 feet was completed in 1970.

FIGURE 26



Miraflores Locks and excavation for third locks at left. Pedro Miguel Lock and Gaillard Cut are in the background.

FIGURE 27



The Panama Canal is now lighted throughout its length and operates around the clock.

FIGURE 28

Route 5 Lock Canal (Figure 29)

Data available from 1931, 1947, and 1964 studies of the 167-mile route in Nicaragua indicate that a lock canal capable of accommodating 110,000 DWT ships and having approximately the same annual transit capacity as the existing Panama Canal would cost about $4 billion. A lock canal designed to meet the 150,000 DWT ship size and 35,000 annual transit capacity criteria would cost much more.

Route 8 Sea-Level Canal Excavated by Either Nuclear or Conventional Excavation

A sea-level canal on Route 8 through Nicaragua and Costa Rica (Figure 29) would cost an estimated $5 billion to construct by nuclear methods, if available, and $11 billion by conventional methods. This latter cost is prohibitive, and nuclear excavation is infeasible for the reasons given in Chapter IV.

Route 17 Sea-Level Canal Excavated by a Combination of Nuclear and Conventional Excavation

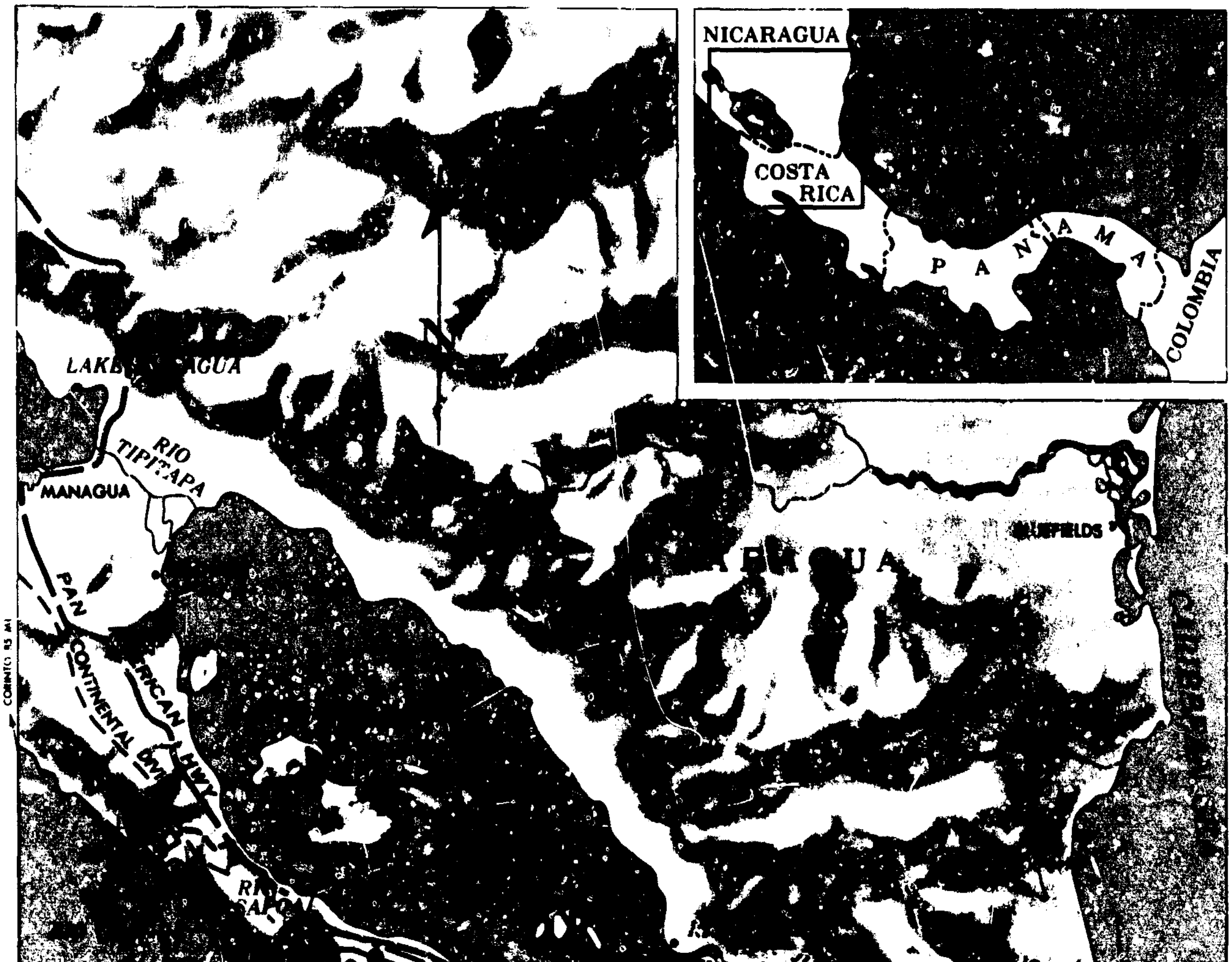
Route 17, approximately 100 miles east of the present Panama Canal (Figure 30) is remote from Panama's developed areas – an essential requirement for nuclear excavation. Approximately 30 miles of its length through the high elevations (that involve the greater portion of the total excavation volume) appear technically suitable for nuclear excavation. Estimated construction costs, assuming partial nuclear excavation would be feasible, total $3.1 billion – more than the estimated cost of all-conventional construction on Route 10 or Route 14.

The problems related to nuclear excavation described in Chapter IV are not the only obstacles to a Route 17 canal. Panama could be expected to object, for the Route would involve major dislocations of the economy of Panama. Panama City and Colon depend upon the present canal and its associated military bases directly and indirectly for some 74 per cent of their economic activity. Although the United States military bases could be left where they are if canal operations were transferred to Route 17, a large phasedown of employment and business activity would accompany the closure of the present canal. The Stanford Research Institute estimates that employment within 30 miles of the present canal would decline by 45,000 with the changeover to Route 17 and only 36,000 new jobs would develop in the new area. The total Panamanian GDP is also estimated to grow somewhat more slowly with the construction and operation of a Route 17 canal than with one on Route 10 or Route 14.

Route 17 offers some military advantages because of its remoteness and its partially nuclear excavated channel (Annex II, Study of Canal Defense). The wide, deep nuclear reaches, comprising three-fifths of the total land cut, would be relatively invulnerable to blockage by scuttled ships, making defense a less difficult problem than on other routes. However, its potential advantages do not now appear to be significant in comparison with the magnitude of the potential problems in nuclear excavation and in transfer of canal operations away from the vicinity of the present canal.

Route 23 Conventional or Combined Nuclear and Conventional Sea-Level Canal

The sea-level canal on Route 23 (Figure 30), proposed by a representative of the Government of Colombia, would have a length of 146 miles, including more than 27 miles



LOCK CA [illegible] UTE 5

SEA-LEVEL CANAL ROUTE 8

FIGURE 29

SCALE IN MILES

10 0 10 20 30

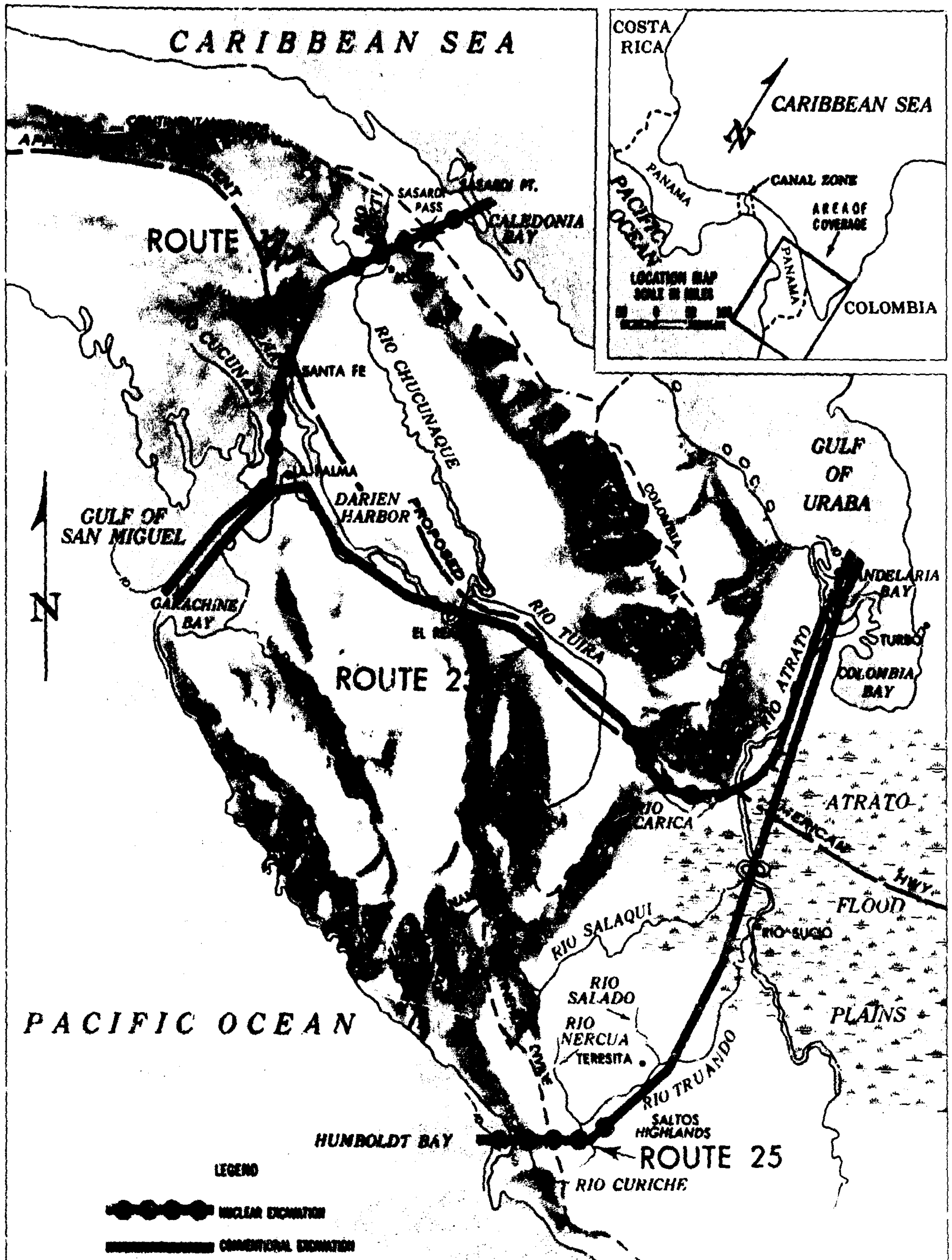


FIGURE 30

SEA-LEVEL CANAL ROUTES
17, 23, AND 25

SCALE IN MILES

5 0 5 10 15 20 25 30 35

DEPTHS IN FATHOMS

Line camp at 1000 foot elevation where Route 17 crosses the Continental Divide

FIGURE 31

of seaward approach channels. This alone makes it non-competitive with other routes. Approximately one-third the length would be in Colombia, generally along the trace of Route 25, and two-thirds in Panama. The Pacific terminus would be the same as for Route 17 and its Caribbean terminus the same as for Route 25.

Were nuclear excavation feasible, about 20 miles through the Continental Divide would be excavated by nuclear explosives. The remainder at lower elevations would be conventionally excavated. Construction costs, based on the limited data available, are estimated to range from $2.4 billion with partial nuclear excavation to $5.3 billion for excavation wholly by conventional methods.

The great length of a Route 23 sea-level canal would involve greater operating and maintenance costs than would other routes. Although there could be political advantages in having a canal pass through two host countries, the technical disadvantages of Route 23 and the obvious economic disadvantages for Panama in a remote canal that shared its revenues with Colombia combine to eliminate this route from further consideration.

Route 25 Conventional and Nuclear Sea-Level Canal

Route 25 (Figure 32) is wholly within Colombia near the Panamanian border. It is approximately 200 miles east of the existing Panama Canal. Its total length is 101 miles. A

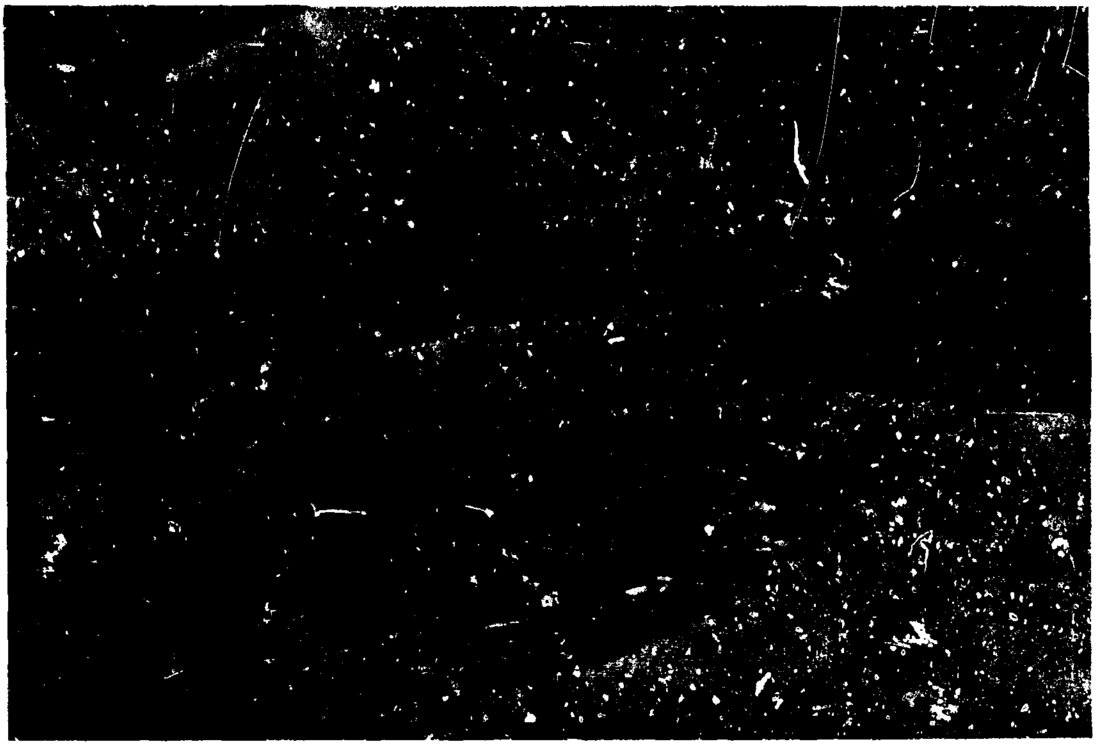
FIGURE 32

SEA-LEVEL CANAL ROUTE 25

SCALE IN MILES

5 0 5 10 15 20 25 30 35

DEPTHS IN FATHOMS



The town of Rio Sucio on the bank of the Atrato River. Excavation of this section of Route 25 through the flood plain of the Atrato River would be accomplished by hydraulic dredging.

FIGURE 33

sea-level canal on this route would not be competitive in cost with other routes without the economies promised by nuclear excavation.

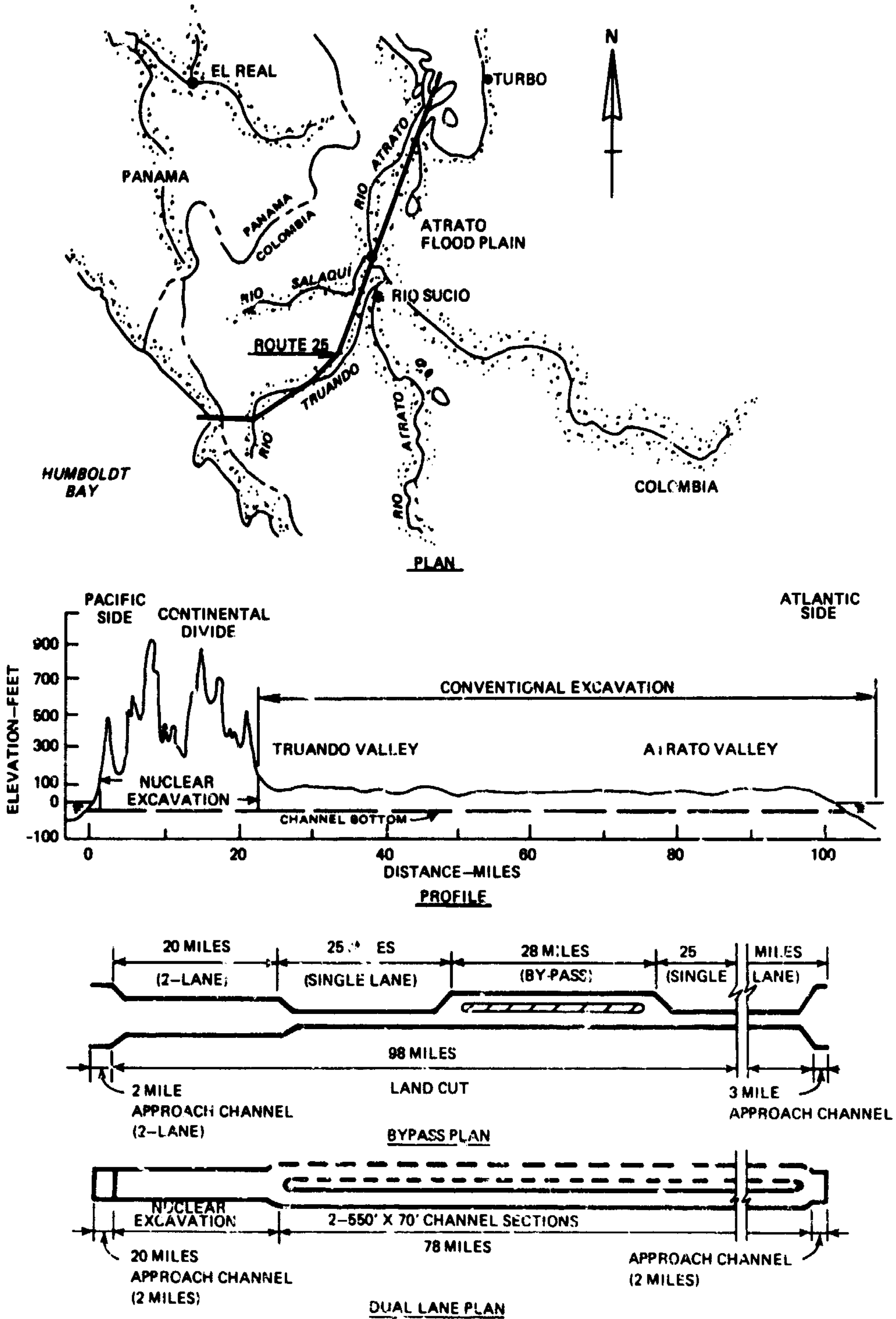
Approximately 20 miles of Route 25 through the Continental Divide, the upper Truando River Valley, and the Saltos Highlands would be excavated by nuclear explosives. The remainder of the route, starting with elevations below 75 feet in the Truando Valley, would be excavated conventionally almost entirely by hydraulic dredging. Most of this portion of the route is through the flood plain of the Atrato River at elevations only a few feet above sea level. At isolated high spots and at the juncture of the nuclear and conventionally excavated reaches conventional dry excavation methods would be used.

Hydraulic excavation along nearly 80 miles of Route 25 at low elevations would be relatively inexpensive, and the incremental costs of wider channels would be small in comparison with the costs of wider channels on other routes.

Two alternatives, shown schematically in Figure 34, are:

- The single bypass configuration.
- The dual lane configuration.

In order to meet the initial 35,000 annual transit capacity criterion, the length of the route would require at least one bypass, which ideally should be located in the center of the single-lane channel and be equal to one-third the length of that channel. The 101-mile length



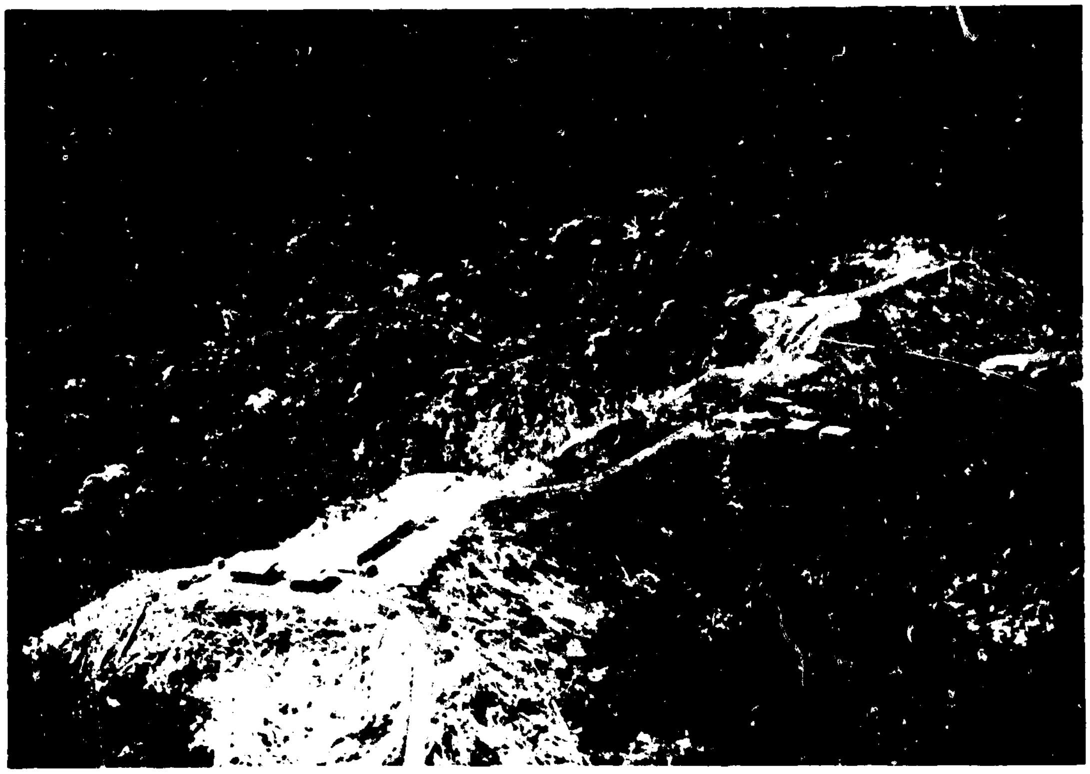
ROUTE 25 CHANNEL CONFIGURATIONS

FIGURE 34

of a canal on Route 25 would limit peak tidal currents to 3 knots. The capital cost of this canal has been estimated, as shown in Annex V, to be $2.1 billion. However, as stated in the report of the Commission's Technical Associates:

***

A valid comparison cannot be made between Routes 10, 14C and 14S, all of which would be excavated entirely by conventional means, and Routes 17 and 25, both of which require nuclear excavation for the planned construction. Nuclear excavation is not yet a proven construction technique and there is no assurance that construction plans and cost estimates based on present knowledge are valid. Therefore, dollar cost comparisons at this time have no true significance.



Alto Curiche weather station near southern end of Route 25

FIGURE 35

Colombia's lack of enthusiasm for a United States-controlled canal on her territory is discussed in Chapter II, and the current uncertainties in regard to the feasibility of nuclear canal excavation are described in Chapter IV. However, both the technical and political prospects of eventually employing nuclear explosives for canal excavation appear more promising for Route 25 than for any other route.

Defense of a sea-level canal on Route 25 would present complex problems. Its land length is nearly three times that of routes in Panama, and all defense facilities – buildings, roads, airfields, etc. – would have to be provided. It is unlikely that United States military

forces could be stationed in Colombia. Although the Colombian armed forces would be capable of providing a measure of security for a Route 25 canal, outside assistance would be required to provide a level of security acceptable to the United States.

A critical defense problem that would accompany construction on Route 25 is that of security of the present canal during the 10- to 15-year construction period. If construction were undertaken as a result of inability to reach agreement in negotiations for a new canal in Panama, a hostile environment would almost certainly develop. In this event, defense of the existing canal could be difficult and expensive.

At the present, a canal in Colombia controlled by the United States appears neither desirable for the United States nor acceptable to Colombia. Should construction of a new canal elsewhere be long deferred and the practicality of nuclear canal excavation be proved in the meantime, it is possible that other factors bearing on the acceptability of a sea-level canal in Colombia would have changed and Route 25 would merit reconsideration.

The Third Locks Plan

There have been many proposals for increasing the capacity of the present canal by construction of additional locks. The most promising are variations of two basic plans: The Third Locks Plan and the Terminal Lake Plan. The former was actually initiated in 1939 and discontinued after expenditure of approximately $75 million on excavations for larger locks adjacent to the existing ones. The new locks would have been 140 feet wide, 1200 feet long, and 50 feet deep. Locks of this size would accommodate vessels of up to approximately 110,000 DWT.

The Terminal Lake Plan would consolidate Miraflores and Pedro Miguel Locks on the Pacific side, raising Miraflores Lake to the level of Gatun Lake. In the process a third lane of locks would be added on both the Atlantic and Pacific sides. This plan has the advantage of providing an anchorage area above the Pacific locks which would eliminate navigation hazards now encountered in that area. A variation of the Terminal Lake Plan, proposed by S.2228 and H.R. 3792, 91st Congress, provides for three lanes of locks, the largest being 140 feet wide, 1200 feet long, and 45 feet deep. The Pedro Miguel Lock would be eliminated and the operating level of Gatun Lake would be raised 5 feet to a maximum of 92 feet above sea level.

None of the proposed lock plans would provide for the transiting of 150,000 DWT ships, the minimum size that would enable the canal to compete with alternate routing for bulk cargo. Hence, a Deep Draft Lock Canal Plan was developed that incorporates the best features of the proposed plans with locks (160 feet by 1450 feet by 65 feet) capable of accommodating 150,000 DWT ships. This plan (Figure 36) provides a reference base for evaluation of sea-level canal alternatives. Table 15 summarizes its characteristics and costs.

None of the proposed lock plans, including the Deep Draft Lock Canal Plan, would permit transit of the United States Navy's largest aircraft carriers which have angled flight decks too wide for the locks. The estimated construction cost of locks adequate for these carriers was $800 million more than the cost of locks for 150,000 DWT ships. Therefore, a lock canal capable of transiting these carriers was given no further consideration.

The addition of a third lane of locks would increase annual transit capacity by approximately 8,000, making the toal annual capacity 35,000. This capacity could

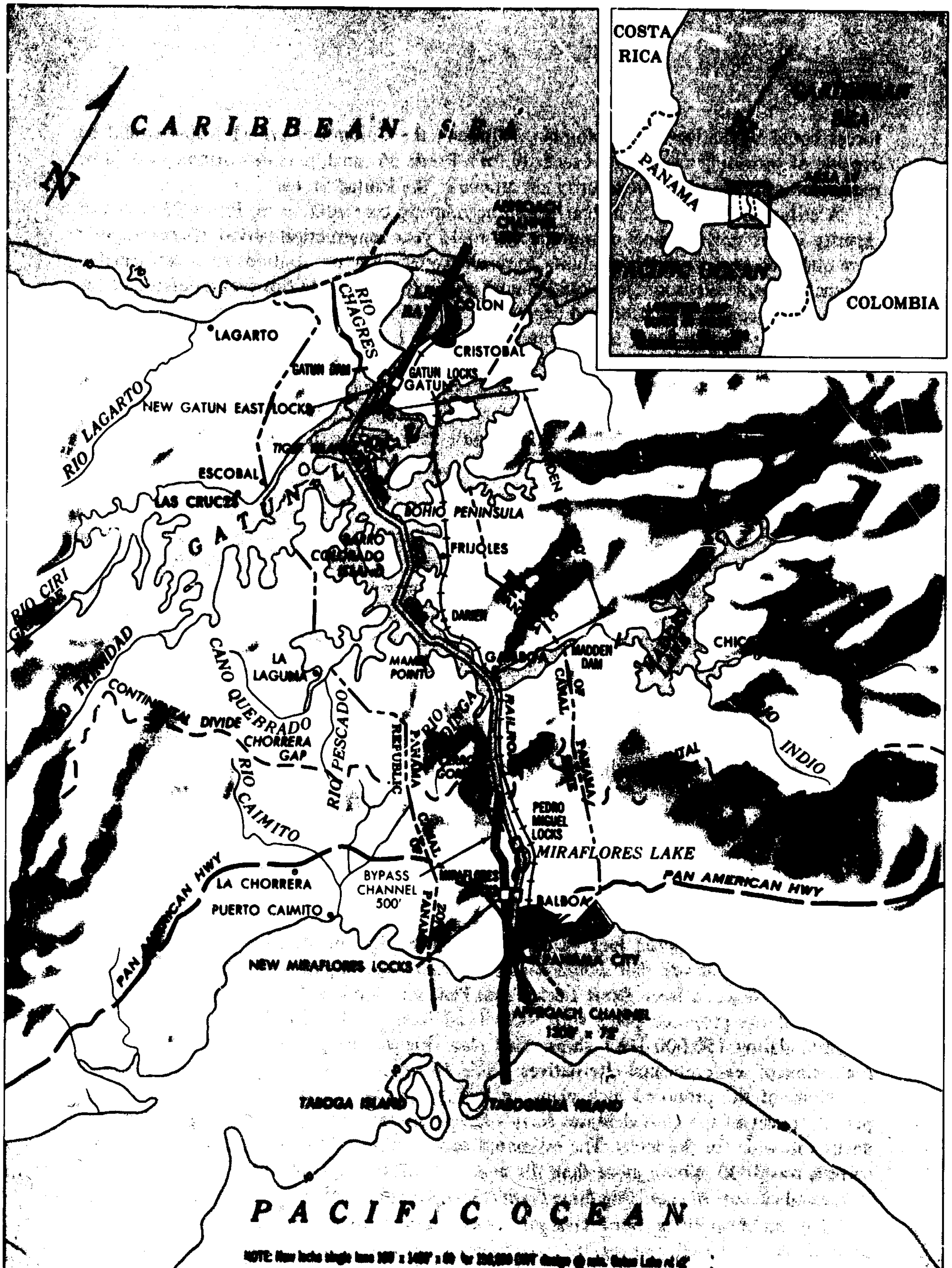


FIGURE 36

DEEP DRAFT LOCK CANAL

SCALE IN MILES
5 0 5 10

DEPTH IN FATHOMS

TABLE 15

ROUTE 15 DATA ESTIMATES

Total construction cost	$1,530,000,000
Channel excavation volume	560,000,000 cubic yards
Channel excavation cost	$570,000,000
Cost of new locks	$550,000,000
Construction time	10 years
Operation and maintenance costs	$71,000,000/year (for 35,000 transits)

These data are based on construction and operation of a deep draft lock canal with a land cut of 36 miles and 20 miles of approach channels. Eight miles will have a 500- by 65-foot channel (75-feet deep at centerline). The remainder will accommodate two-way traffic. A third lane of locks will be added to the existing locks. They will be 160- by 1450- by 65-feet and will accept 150,000 DWT ships.

This improved lock canal would have an effective capacity of 35,000 transits per year. At this capacity, the time lost by the average ship in slowing down, awaiting its turn to enter the canal, transiting, and then regaining open ocean speed is estimated to be about 25 hours.

meet projected demands for commercial transits through this century at a lesser cost than that of a sea-level canal. This is its only major advantage. However, expansion to meet further traffic growth would not be practicable.

The United States has held that the provisions of the Treaty of 1903 permit the building of a third lane of locks. This may not be a practicable alternative because a controlling determinant of the long-term viability of any course of action in Panama is its acceptability to the government and people of Panama, the United States, and, hopefully, to Latin America generally. It seems obvious that major augmentation of the existing canal would not serve United States interests unless accomplished under a new treaty arrangement or major revision of the present treaty willingly entered into by Panama.

Augmentation of the existing canal under treaty arrangements comparable with those proposed in 1967, with an appropriate extension of the period of United States control, would have favorable effects on the economy of Panama (see Annex I, Foreign Policy Considerations). The political disadvantage of the third-locks solution is that it would tend to increase operating personnel and defense requirements that are currently causes of concern to Panama.

Construction of a third lane of locks would not reduce the vulnerability of the lock canal to long-term interruption by sabotage or military attack. The critical weaknesses of the locks and the high level lake would remain unchanged. The basic vulnerability of the

lock canal would continue to require large defense forces on site and provisions in United States strategic plans for the contingency of long-term closure of the canal in wartime. The lock canal's current inability to transit the Navy's aircraft carriers would continue.

Route 14 Conventionally Excavated Sea-Level Canal

The two alinements of Route 14 that were evaluated are identical except through the Continental Divide (see Figure 37). Both follow the trace of the present Panama Canal without its many angularities. Route 14 Combined (14C) would involve deepening and widening of the present Gaillard Cut; Route 14 Separate (14S) would require a new cut through the Divide about one mile to the southwest of the present cut. Both alinements pass under the existing bridge at the Pacific end of the present canal and utilize excavation already accomplished for the unfinished third locks project.

The combined cut offers considerable savings in the volume of excavation because of the lower elevation through the Divide. However, only the separate cut permits excavation in the dry to project depth in the Continental Divide area. A major disadvantage of the combined alinement is its inevitable interference with the operation of the existing canal during the ten or more years of actual construction. The Gaillard Cut is now only 500 feet wide and must be operated on a one-way basis for the largest ships that transit the canal. Cut widening and deepening would further limit capacity during the construction years. Excavation to 85 feet below sea level in this cut could induce slides that would block the existing canal for long periods. These and other potential disadvantages of Route 14C discussed in detail in Annex V led the Commission to conclude that Route 14S would be the preferable sea-level canal alinement within the existing Canal Zone, regardless of its slightly greater cost.

Three feasible design configurations for Route 14S have been considered (Figure 38). Two include a centrally located single-lane section while the other includes two parallel single-lane sections; all sections are cut to the design channel criteria. Each configuration includes 1400 by 85 foot two-lane approach channels at both its Atlantic and Pacific ends. The configurations, in the ascending order of cost and capacity, are:

- A 33 mile single-lane section.
- A 24 mile single-lane section.
- Two parallel 19 mile single-lane sections.

Each of these could be constructed with check gates to limit the tidal currents. The location of the tidal checks would vary with the configuration and the maximum acceptable current. The methods of operation with tidal gates in the various configurations of Route 14S, channel design, and convoy operations would be essentially the same as for Route 10, discussed later in more detail. The initial transit capacity would be at least 35,000 annually.

The topography of Route 14S does not lend itself to a bypass, which should be located along the center third of a canal alinement to be effective. Consequently, the logical expansion steps involve progressive shortening of the one-way section by extending the Atlantic approach across Gatun Lake, where elevations are much lower than those close to the Pacific. The maximum currents in the single-lane section would tend to increase as this section became shorter, but tidal gates could provide appropriate control. Shortening the restricted section would significantly increase capacity.

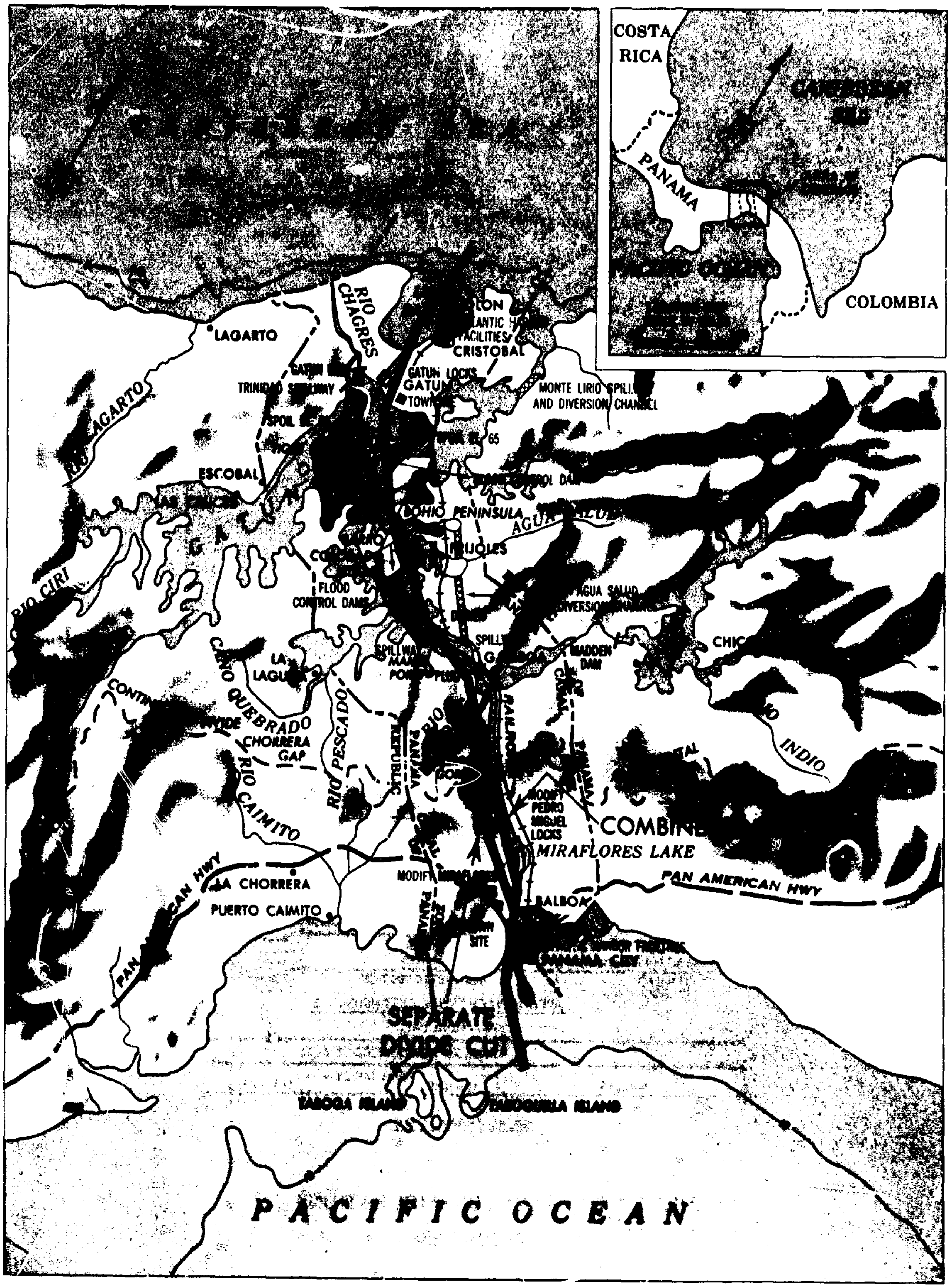
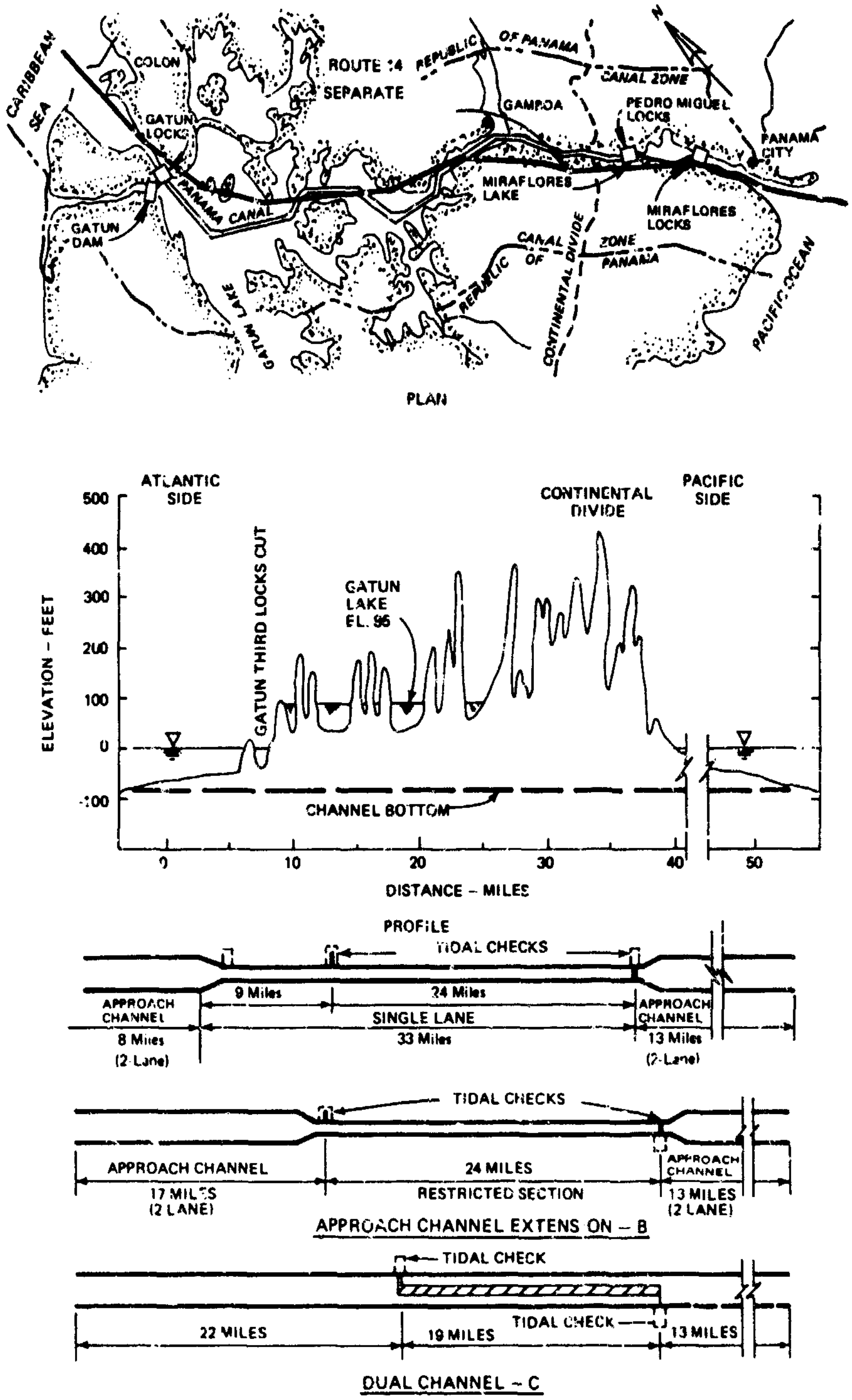


FIGURE 37

SEA-LEVEL CANAL ROUTE 14

SCALE IN MILES
5 0 5 10
DEPTH IN FATHOMS



ROUTE 14S CHANNEL CONFIGURATIONS

FIGURE 38

In the final phase of construction of a sea-level canal on Route 14S the water in the channel would be lowered from the level of Gatun Lake to sea level. This would be accomplished by removal of the plugs left at either end of Gatun Lake and the simultaneous construction of an earth dam in the old canal channel near Gamboa to divert the Chagres River to the Pacific. This drawdown would create a hazard of slides. As much as three months would be required for the changeover, during which time there could be no traffic through the canal.

Political factors bearing on the feasibility of a sea-level canal on any route within or near the Canal Zone and the effects upon the economy of Panama would not be measurably different (Annex I). Route 14 has the advantage, however, of being wholly within the Canal Zone. Construction on Route 14 would require no acquisition of privately owned land and would create the minimum local disturbances.

TABLE 16

ROUTE 14S DATA ESTIMATES

Total construction cost	$3,040,000,000
Channel excavation volume	1,950,000,000 cubic yards
Channel excavation cost	$2,210,000,000
Construction time	16 years (includes 2 years for preconstruction design)
Operation and maintenance cost	$56,000,000/year (for 35,000 transits)

These data are based on construction and operation of a sea-level canal with a 33 mile single-lane land cut and 21 miles of two-lane approach channels. Ships up to 150,000 DWT could be accommodated under all conditions; larger ships up to 250,000 DWT could be accommodated under controlled conditions. Tidal gates would be installed and used continuously to limit current to no more than 2 knots.

This configuration would have an effective capacity of 39,000 transits/year. At this capacity, the time lost by a ship in slowing down, forming into a convoy, passing through the canal, and regaining open ocean speed would be comparable to time lost by a ship passing through the Panama Canal in 1970. At lower traffic levels, time lost would be significantly less.

If experience showed that additional capacity would be required, the two-lane approach channel on the Atlantic end could be extended inland across Gatun Lake for 9 miles, reducing the single lane reach to 24 miles. The cost of this additional effort would be $430,000,000 The new configuration would have an effective capacity of 55,000 transits/year.

Interference with traffic through the existing canal during construction of a sea-level canal and the ultimate elimination of the existing canal and the partial elimination of Gatun Lake would be significant disadvantages from both United States and Panamanian viewpoints.

Route 14 1 , the military advantage of being in practically the same location as the Panama Canal for which all existing defense installations have been sited, but there are two disadvantages to Route 14 from the defense viewpoint: the vulnerability of the existing canal during the construction period to interruption by slides or by military attack would be greater than at present, and there would be many miles of barrier dams to defend along each side of the sea-level canal across Gatun Lake.

Route 10 Conventionally Excavated Sea-Level Canal

Route 10 (Figure 39) is approximately 10 miles to the west of the existing Panama Canal. With the exception of two short reaches across arms of Gatun Lake, the route lies outside the present Canal Zone. The area is undeveloped except for a few small farms and grazing lands interspersed with jungle. The proximity of the Canal Zone would permit use of existing Panama Canal facilities in support of canal operations.

An analysis of possible sea-level canal configurations on this route leads to three distinct alternatives, each of which would be 36 miles in length between two double-lane approach channels 1400 feet wide and 85 feet deep (Figure 40). Listed in ascending order according to capacity and cost, they are:

- A single-lane channel for the full length of 36 miles.
- An 11 mile single-lane channel on each end connecting with a 14 mile centrally located bypass section consisting of two single-lane channels.
- Two parallel 36 mile single-lane channels separated by a berm.

This order is also the sequence in which the canal could be constructed to provide progressively greater capacity. The ultimate capacity would be reached by extension of the bypass across the Isthmus, providing two parallel one-way channels.

A combination of conventional excavation techniques would be used. A system of barrier dams would be employed to isolate the construction area from Gatun Lake and the present canal and thereby permit excavation in the dry of the bulk of the material.

Table 17 gives the capacity-cost data for the single lane configuration.

Prism design and ship spacing have been based on operating in 4-knot currents, but the Commission considered it prudent to base initial capacity calculations on tidal currents being limited to 2 knots and to incorporate into conceptual designs and cost estimates the facilities required for that purpose. The installation of a tidal control structure at the Pacific entrance and another 25 miles north thereof in the basic one-way channel would accomplish this purpose and permit more than 35,000 transits per year.

Past negotiations indicate that a sea-level canal on Route 10 should be acceptable to Panama under reasonable treaty conditions. The precise treaty provisions can be determined only by further negotiation, but the objectives of the United States and Panama in any canal on Panamanian territory do not appear to be irreconcilable.

Construction of a canal on Route 10 would not bring about any shift of canal operations from near Panama's metropolitan centers. The avoidance of interference with traffic during the construction phase and the preservation intact of the existing canal after a

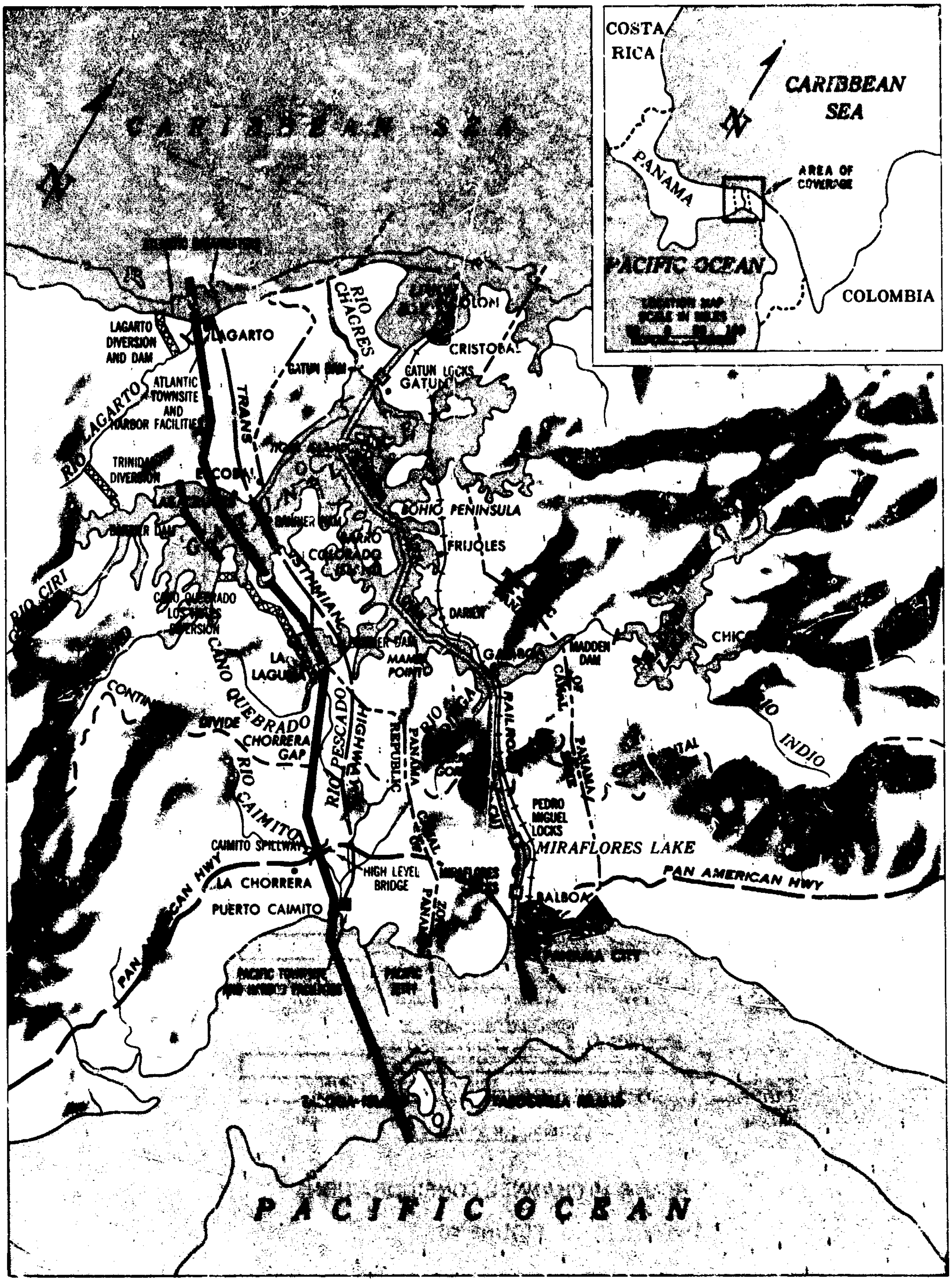


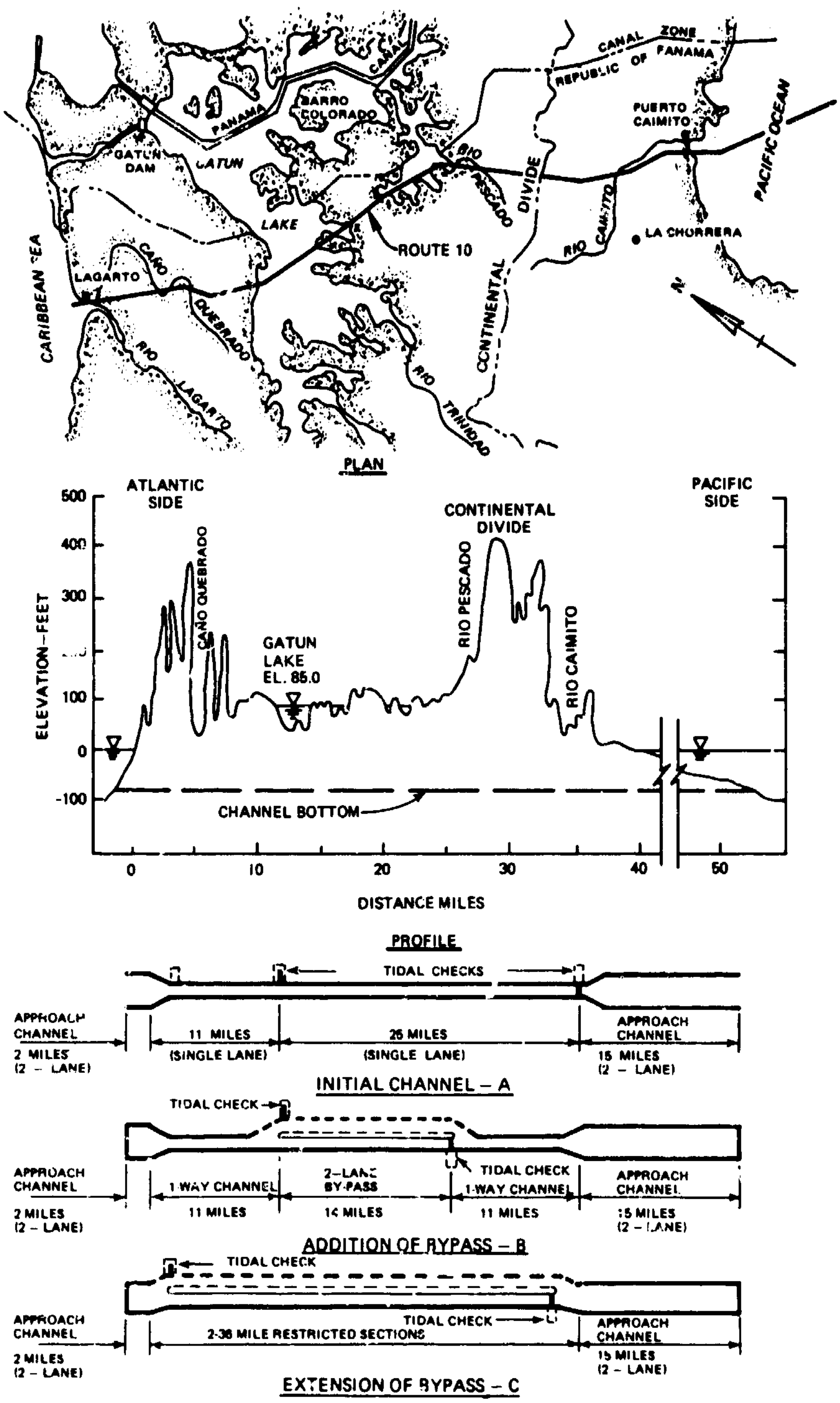
FIGURE 39

SEA-LEVEL CANAL ROUTE 10

SCALE IN MILES

5 0 5 10

DEPTH IN FATHOMS



ROUTE 10 CHANNEL CONFIGURATIONS

FIGURE 40

TABLE 17

ROUTE 10 DATA ESTIMATES

Total construction cost	$2,880,000,000
Channel excavation volume	1,870,000,000 cubic yards
Channel excavation cost	$2,030,000,000
Construction time	14 years (includes 2 years for preconstruction design)
Operation and maintenance cost	$57,000,000/year (for 35,000 transits)

These data are based on construction and operation of a sea-level canal with a 36-mile single-lane land cut and 17 miles of two-lane approach channels. Ships up to 150,000 DWT could be accommodated under all conditions; larger ships up to 250,000 DWT could be accommodated under controlled conditions. Tidal gates would be installed and used continuously to limit current to no more than 2 knots.

This configuration would have an effective capacity of 38,000 transits/year. At this capacity, the time lost by a ship in slowing down, forming into a convoy, passing through the canal, and regaining open ocean speed would be comparable to time lost by a ship passing through the Panama Canal in 1970. At lower traffic levels, time lost would be significantly less.

If experience showed that additional capacity would be required on this route, a 14-mile bypass would be constructed for about $460,000,000. It would have an effective capacity of 56,000 transits/year and, at all levels of capacity, would allow less time in transit than a single-lane canal.

new canal is opened would have distinct advantages for Panama. Construction of a canal on Route 10 would permit future operation of the existing canal in combination with the sea-level canal and leave Route 14 available for construction of a second sea-level canal if one were ever needed.

While the advantages for Panama in either a Route 14 or a Route 10 sea-level canal should make either acceptable under a mutually satisfactory treaty arrangement, the comparative advantages and disadvantages on balance favor Route 10. In any arrangement for operation of a sea-level canal on Route 10, it would be unacceptable for the present canal to pass to Panamanian control and be operated in competition with the sea-level canal.

The Stanford Research Institute's study of sea-level canal economic impacts estimated that the maximum reduction in canal employment for a sea-level canal on Route 10, in comparison with continuing the present lock canal, would be 6,300 employees. On the

other hand, more than 7,000 employees would be needed during the sea-level canal construction period. The foreign exchange earnings for Panama from sea-level canal construction, estimated to be more than $1 billion, plus the greater long-term earnings from the new canal capacity, would permit greater total economic development and employment in Panama than continuation of the existing canal. The Stanford Research Institute estimated that the gross domestic product (GDP) and total employment in Panama would not only grow rapidly during the sea-level canal construction years but also would thereafter continue to be greater than it would be were the present canal continued under the existing treaty (Annex I).

One disadvantage of Route 10 is that it lies outside the existing Canal Zone. Construction on it would require acquisition of some privately owned land, but the needed land is relatively undeveloped and its acquisition should involve no significant problems or cost. The question of jurisdiction in the canal area is not material to the choice of sea-level canal routes in Panama, inasmuch as a new treaty is expected to be negotiated for construction on any route. Resolution of the issues of Panamanian sovereignty and jurisdiction of the canal operating authority should affect all routes equally.

Defense of a sea-level canal on Route 10 would require only limited expenditures for new defense facilities, such as helicopter landing areas, access roads, and facilities at the canal entrances for small Navy elements. The additional distance to Route 10 is so small that all major defense requirements would continue to be met by existing military installations in the Canal Zone. Not only would a sea-level canal on Route 10 be far less vulnerable than a lock canal, but also it would be somewhat less vulnerable than one on Route 14 with its more extensive barrier dams needed to preserve Gatun Lake.

The distance of Route 10 from the metropolitan centers of Panama City and Colon is a slight military advantage, but continued use of existing Zone facilities in support of a canal on Route 10 would leave many facilities and canal personnel in the same location regardless of the choice of Route 10 or Route 14.

The major military advantages of Route 10 over Route 14 are that construction on Route 10 would avoid the long period of vulnerability of the existing canal during construction of a sea-level canal adjacent to it on Route 14, and the additional capacity and safety offered by the continued availability of the old canal after a new one is opened on Route 10.

Route 10 Sea-Level Canal Operated in Combination with the Existing Lock Canal as One System

The present canal would continue in operation during the construction period of any sea-level canal. When the sea-level canal is opened, the existing canal would be needed to provide an emergency alternative until the new canal had been operated for a period of years, its capabilities proved, and there was reasonable certainty that it would not be seriously affected by slides. The Commission has been advised by its Technical Associates for Geology, Slope Stability, and Foundations that 10 years is a minimum period for this purpose. It would be desirable also to maintain it on a standby basis for an extended period thereafter.

The existing canal with improvements short of additional locks has, as previously been indicated, a potential annual transit capacity of 26,800 ships of all sizes below 65,000 DWT.

Farmland on southern portion of Route 10

FIGURE 41

In the mix of ships projected for Isthmian canal traffic in the year 2000 and thereafter, more than 85 per cent of the total continues to be in these smaller sizes. Although the combined capacities of the old canal and a sea-level canal on Route 10 are not likely to be needed in this century, it would be unwise for the United States to commit itself to discard the old canal permanently until the lack of ultimate need for it was certain.

There are no unique engineering problems in maintaining the lock canal on a standby basis. The cost of operating it on a one-shift basis after a new canal is opened is estimated to be approximately $4 million a year. This amount would provide for personnel for maintenance and operation, dual training of sea-level canal operating personnel for lock canal operations in an emergency, and periodic channel dredging. When no longer needed, maintaining it on a non-operating standby status is estimated to cost $1 million a year.

Integration of the operation of a new canal on Route 10 with operation of the existing canal would have great advantages over operation of a canal on Route 10 as a separate entity.

If a new treaty should authorize such a system, all feasible alternatives for providing canal capacity greater than now existing would be available. Initial expansion could be accomplished by adding lock lanes to the existing canal or by building a sea-level canal on Route 10. Subsequent needs in excess of the minimum capacity of the sea-level canal could be met in three different ways:

1. Reactivating the existing lock canal,
2. Providing a bypass on Route 10, and
3. Constructing a second sea-level channel either along Route 10 or generally along the trace of the existing canal (Route 14).

Reactivating the lock canal would permit a total of at least 60,000 annual transits; addition of a bypass to the sea-level channel on Route 10 would permit approximately 56,000 annual transits; Route 10 with a bypass in combination with the existing lock canal would permit at least 80,000 annual transits; a second sea-level channel would permit well in excess of 100,000 annual transits.

This flexibility in future canal possibilities, providing as it would maximum transits and other economic benefits, would be as advantageous to Panama as to the United States. Such a system should be welcomed also by all canal-using nations as indicative of the intent of the United States and Panama to ensure adequate canal capacity indefinitely.

The Stanford Research Institute's evaluations of the economic impacts of various sea-level canals showed that the combined operation of the old and new canals would be the most beneficial to Panama of all the plans considered. Appropriate Canal Zone facilities would continue to be used by the canal system operating authorities to administer and support canal-system operations and the Canal Zone military bases would continue in essentially the present status for defense. In addition, however, maintenance of the old canal in service, or even on a standby status, would create, directly and indirectly, more jobs for Panamanians than would a sea-level canal on Route 10 alone and would generate greater foreign exchange earnings for Panama.

Adoption of the system concept would not foreclose relinquishment to Panama of excess Canal Zone properties such as contemplated in the 1967 draft treaties. Zone water resources, unneeded facilities, and excess land areas that could be made available to Panama were a sea-level canal operated alone on Route 10, would be almost equally available were the channels and locks of the existing canal maintained for reactivation when needed.

The defense advantages of a sea-level canal on Route 10 have been discussed above. These advantages would be somewhat greater in the canal system as envisioned because the present canal would be useful if the sea-level canal were blocked. Defense of the standby canal should cause no major additional problems. The existing military bases are already suitably sited, and the forces planned for the defense of Route 10 could, with acceptable risks, provide protection for the standby facilities. In periods of increased tension, defense forces could be augmented as necessary.

CHAPTER VIII

FINANCIAL FEASIBILITY

The financial feasibility of the sea-level Isthmian Canal is dependent on a number of variables, none of which can with confidence be assigned a value. The Commission had to consider a range of values for some and make reasonable assumptions for others as described in this Chapter. Detailed discussions of these matters and financial analyses of sea-level canal arrangements and the third-locks alternative are contained in Annex III, Study of Canal Finance. The discussion in this Chapter is directed primarily to the financial feasibility of construction of a sea-level canal on Route 10 that would be operated in conjunction with the existing Panama Canal as a single system.

Considerations for Financial Analyses

Revenues

Revenues expected from tolls on a sea-level canal at current toll rates and the maximum potential under an increased toll schedule are summarized in Table 18:

TABLE 18

FORECASTS OF SEA-LEVEL CANAL REVENUES
Millions of Dollars

	Potential Tonnage Forecast		Low Growth Forecast	
Fiscal Year	Current Tolls	Maximum Tolls	Current Tolls	Maximum Tolls
1990	205	287	185	259
2000	290	406	215	301
2010	391	546	235	329
2020	500	700	264	370
2030	577	811	282	392
2040	605	847	313	440

Costs of Operations

The Panama Canal Company and Canal Zone Government now conduct many revenue-producing activities not directly connected with operating and maintaining the canal. The costs of these operations taken together approximately equal their total revenues. Government functions, such as police and education, are financed from general revenues.

In estimating the operating costs of a sea-level canal, the Commission included only those activities directly associated with canal operation and maintenance, including administrative overhead. Commercial and government activities were assumed to be neither a cost nor a source of revenue in sea-level canal operations.

Payment to Host Country

The unratified 1967 draft of a treaty with Panama for the continued operation of the present canal would have replaced the 1955 Treaty provision for a fixed $1,930,000 annuity to Panama with royalty payments for each long ton of cargo transported through the canal. The draft suggested that the royalty payment start at 17 cents per long ton of cargo and rise 1 cent annually for 5 years to 22 cents per long ton, at which level it would remain. This 1967 plan has recently been rejected by Panama and is in no way binding upon the United States. The Commission, however, used, for purposes of comparison, the suggested royalty payments as one possible compensation arrangement in estimating the total cost of operating a sea-level canal in Panama.

The level of host-country compensation that might be required for a canal in Colombia cannot be established until the United States is prepared to discuss detailed canal treaty terms with the government of that country. Meaningful estimates of the operating revenues of a sea-level canal in Colombia require assumptions as to what use would be made of the existing canal subsequent to the opening of the new canal. The Commission could find no basis for such assumptions and hence was unable to make a financial analysis of a sea-level canal on Route 25, except to recognize that competition by the existing Panama Canal could make it impossible for the new canal to meet operating costs and debt service charges from revenues.

Inflation

The inflation of costs over time is an established trend that cannot be disregarded in financial analyses of prospective sea-level canals. Maintenance of the Panama Canal tolls at the same dollar level for more than a half a century was made possible only by political decisions that reduced costs funded from tolls. Similar decisions could be made in financing a new canal, but they were not assumed in developing the financial analyses in Annex III, Study of Canal Finance.

A self-amortizing sea-level canal would require provisions in its financial plan to compensate for the effects of inflation. However, reliable estimates of the effects of inflation on costs and revenues for a 75-year period into the future are not possible; attempting to incorporate them would not add to the validity of the financial analyses. The conclusion was reached in the evaluation of the toll revenue potential of a sea-level canal in Annex IV, Study of Interoceanic and Intercoastal Shipping, that costs of alternatives to using the canal will tend to increase in parallel with increases in canal costs, and tolls could be increased in proportion without discouraging traffic growth materially. Therefore, the assumption was made that future tolls would be increased periodically in proportion to inflation of costs. All estimated costs and revenues, therefore, are stated in 1970 dollars.

Construction and Amortization Periods

Estimated construction periods vary only slightly among canal routes, but estimates of the time required for negotiations with the host country and the passage of appropriate

legislation can only be approximations. The Commission has assumed that the time from the date of decision to construct a sea-level canal to the date of its opening would be 15 years, regardless of the route chosen.

The 1967 draft treaties with Panama suggested 60 years of United States control of a sea-level canal after its opening. Inasmuch as a longer period would not materially change amortization prospects, the Commission selected 60 years as an appropriate period for financial analyses.

Interest Rates

The discount rate on the investment in a new sea-level canal will be a major determinant of its financial feasibility. The interest on the debt of the present canal to the United States Treasury is assessed at the average rate of all of its outstanding debt, computed for Fiscal Year 1969 to be 3.69 per cent per annum. In Fiscal Year 1970 the interest rate used in analyzing federally financed water resources projects was 5.5 per cent. At the time of preparation of this report, however, long-term United States Government bonds were selling in the open market at yields in the neighborhood of 7 per cent. The Study of Canal Finance (Annex III) suggests no basis for an early decline in interest rates, although the current rate is historically high. The Commission considers 6 per cent per annum to be a reasonable estimate of minimum long-term financing costs of sea-level canal investments that would be spread over a 15-year period. However, the effects of a range of interest rates up to 12 per cent are analyzed in Annex III.

Debt of the Panama Canal

Two assumptions were made regarding the interest-bearing debt to the United States Treasury of the Panama Canal Company:

1. The debt would continue to be an obligation of a new canal operating authority that controlled both the existing canal and a sea-level canal as a single system;
2. The debt would be written off if the sea-level canal operating authority did not control the old canal and the new canal were operated as a separate entity.

Financial Analyses of Canal Alternatives

The annual rate of expenditure for construction of a sea-level canal should not materially exceed $300 million in any year and would average about $200 million per year over a 15-year construction period. These annual capital expenditures, together with interest charges, could in some circumstances accumulate to a debt of such magnitude that repayment from canal revenues would not be possible. Although self-amortization has not been required of the present canal, the Commission's financial analyses of the sea-level canal alternatives were designed to determine what combinations of operating costs, payments to the host country, interest rates, canal opening dates, traffic levels, and toll rates would permit recovery of capital costs from toll revenues. These analyses also permit estimation of the capital costs that might have to be written off for other objectives.

The financial prospects of sea-level canal alternatives were examined by the Interdepartmental Study Group on Canal Finance from two different viewpoints. One approach treated the old and new canals as commercial enterprises to determine whether investment in the

new capacity could be justified economically solely by the additional business it could generate. Investment in a sea-level canal cannot be justified on this basis.

The second approach, that considered by the Commission to be the appropriate one, was to determine whether a sea-level canal could be operated on a self-amortizing basis by crediting it with total revenues rather than only those in excess of what might be produced by the existing canal. Analyses also were made of the amortization prospects of a third lane of locks for the existing canal. The results of these analyses are summarized in Table 19 for three alternatives: Route 15 – Lock Canal; Route 10 – Sea-Level Canal as a separate entity; and Route 10 operated as a system in conjunction with the present canal. The analyses of Route 10 as part of a system are set forth for two conditions: changes in toll rates being made at the time the canal goes into operation, and as of the time construction is started.

In each case, the annual costs of operation were taken to be those set forth in Annex V, Study of Engineering Feasibility, and allowance was made for payments to Panama of $0.22 per cargo ton in 1976 and thereafter during the period required for amortization of the capital costs. It was also assumed in each case that all capital costs and interest charges would be amortized from toll revenues.

It was further assumed in the financial analyses of the combination of a sea-level canal on Route 10 and the existing lock canal that the current debt of the Panama Canal Company would also be amortized from toll revenues of this system.

The effects of possible modifications of these assumptions are discussed near the end of this Chapter.

If the sea-level canal on Route 10 were operated as a unit of a system including the Panama Canal, the prospects of amortization would be improved greatly. For example:

1. If the interest rate were 6 per cent and the opening date of the canal were deferred until 1995, no increase in tolls above the present level would be necessary, provided the potential growth of traffic were realized;
2. If traffic were to grow at the low rate, and the average toll were raised to $1.20 per ton with the interest on the debt at 6 per cent per annum, it would only be necessary to defer opening the canal until 2000.

The foregoing analyses of the requirements for amortization have all been based on canal tolls being held at an average of $0.884 per cargo ton until the opening date of a new canal. If, on the other hand, canal tolls should be held at this level only until start of new construction of a canal on Route 10, the requisite average level of tolls would be reduced materially below those required under the previous assumption. Thus:

1. If the potential growth of traffic were to be realized, and the interest rate were 6 per cent per annum, the average toll would have to be only $0.94 per ton if the new canal were opened in 1990;
2. If the opening of the canal were deferred until 1995, no increase above the present level should be necessary under these conditions.

However, if only the low traffic growth rate should be realized, some increase in the average toll would be necessary under any likely combination of interest rates and times of opening of the canal. For example:

1. If Route 10 were completed in 1990 and operated as part of a system and tolls were increased when construction was initiated, the average required toll would be $1.19 per ton;

TABLE 19

AVERAGE TOLL REVENUES PER LONG TON OF CARGO REQUIRED FOR AMORTIZATION OF CAPITAL COST IN 60 YEARS WHILE PAYING PANAMA A ROYALTY OF $0.22 ON EACH TON

Canal Route	Traffic Growth Rate	Canal Opening Date	Average Annual Interest on Debt 4%	5%	6%	7%	8%
Route 15	Potential (1)	1990	$0.65	0.74	0.83	0.95	1.10
New Locks		1995	0.58	0.63	0.71	0.81	0.95
$1.53 Billion		2000	0.49	0.52	0.59	0.67	0.80
Capital cost	Low (1)	1990	0.87	0.98	1.10	(a)	(a)
Annex III		1995	0.79	0.88	0.99	1.20	(a)
Figure A1-24		2000	0.69	0.78	0.87	1.02	(a)
Route 10	Potential (1)	1990	0.69	0.81	0.96	1.14	(a)
Sea-Level		1995	0.65	0.75	0.87	1.02	1.22
by itself		2000	0.62	0.70	0.81	0.93	1.07
$2.88 Billion	Low	1990	0.98	1.20	(a)	(a)	(a)
Annex III		1995	0.97	1.15	(a)	(a)	(a)
Figure A1-1		2000	0.95	1.10	(a)	(a)	(a)
Route 10	Potential (1)	1990	0.69	0.83	1.00	1.28	(a)
Sea-Level with		1995	0.60	0.72	0.85	1.07	1.30
Panama Canal		2000	0.53	0.60	0.71	0.85	1.07
$2.88 Billion	Low (1)	1990	0.98	1.24	(a)	(a)	(a)
Annex III		1995	0.90	1.10	(a)	(a)	(a)
Figure A1-2		2000	0.81	0.96	1.20	(a)	(a)
Route 10	Potential (2)	1990	0.73	0.83	0.94	1.06	1.22
Sea-Level with		1995	0.67	0.76	0.86	0.97	1.10
Panama Canal		2000	0.61	0.68	0.77	0.88	0.98
$2.88 Billion	Low (2)	1990	0.95	1.05	1.19	(a)	(a)
Annex III		1995	0.89	0.99	1.11	1.23	(a)
Figure A1-3		2000	0.83	0.92	1.03	1.14	1.26

(1) Canal tolls held at $0.884 per ton until canal opening date.

(2) Canal tolls held at $0.884 per ton until start of new construction.

(a) Required tolls exceed an average of $1.30 per ton, the rate estimated to produce the maximum revenue from tolls.

2. If the opening date were deferred until 1995, the required toll would be $1.11 per ton;

3. If the opening were deferred until 2000, the required toll would be $1.03 per ton.

Some of the data given in Table 19 are also shown graphically in Figures 42a, 42b, 43a, and 43b, taken from Annex III, Study of Canal Finance.

It follows that, from a financial point of view, construction and operation of a sea-level canal on Route 10 in conjunction with the Panama Canal would be preferable to construction and operation of a sea-level canal on Route 10 as a separate entity; further, the prospects of amortization of the capital cost would be enhanced by appropriate increases in average toll revenues at the time of initiation of construction of a canal on Route 10.

Table 19 does not show the tolls required if a sea-level canal were built on Route 14, but the values for a sea-level canal on Route 10 operated as a separate entity are representative of the tolls that would have to be levied if the canal were built on Route 14. The capital cost of the latter is only slightly greater than the capital cost for a canal on Route 10.

It is also apparent from a financial standpoint that deferment of construction of any new canal would be desirable, because such deferment would permit the payment of either a higher rate of interest on the debt or a lower average level of tolls and still enable the capital costs to be amortized in the first 60 years of operation of any new canal.

Cash Flow

Irrespective of the route or means that may be taken t provide for increases in traffic between the oceans, there will be a period during construction when the expenditures required will exceed all available revenues. Hence, at the end of the construction period a substantial debt will have been accumulated. Thereafter, there will be further accumulations of debt to the extent that the gross revenues from tolls are less than all costs of operation, payments to the host country, and interest on the then existing debt. There will thus be a net cash input until the revenues from tolls becomes sufficiently large to permit progressive amortization of the peak debt.

The results of the calculations of the magnitude of the "peak debt" under different conditions are shown in Table 20 for the case of a sea-level canal on Route 10 operated in conjunction with the existing lock canal. The basic assumptions were again made that payments to Panama would be at the rate of $0.22 per cargo ton and that all capital costs and interest charges would be amortized from toll revenues. The variables in this tabulation are the canal opening dates, the potential and the low rates of traffic growth described in Chapter III, and a range of average toll rates per cargo ton. The toll rates in this tabulation have been considered only as being in effect from the start of construction of a sea-level canal on Route 10.

The peak debt arising out of construction of any other canal, or as influenced by any other date or change from existing toll levels, differs from the values in this tabulation, but the changes would be generally proportional. An interest rate of 6 per cent was used to derive the values in Table 20; if some other rate of interest were used, the changes would also be proportional.

It follows from these data that, from a financial point of view, it would be desirable to defer construction of a new canal as long as practicable. For example: assuming an average

FIGURE 42a

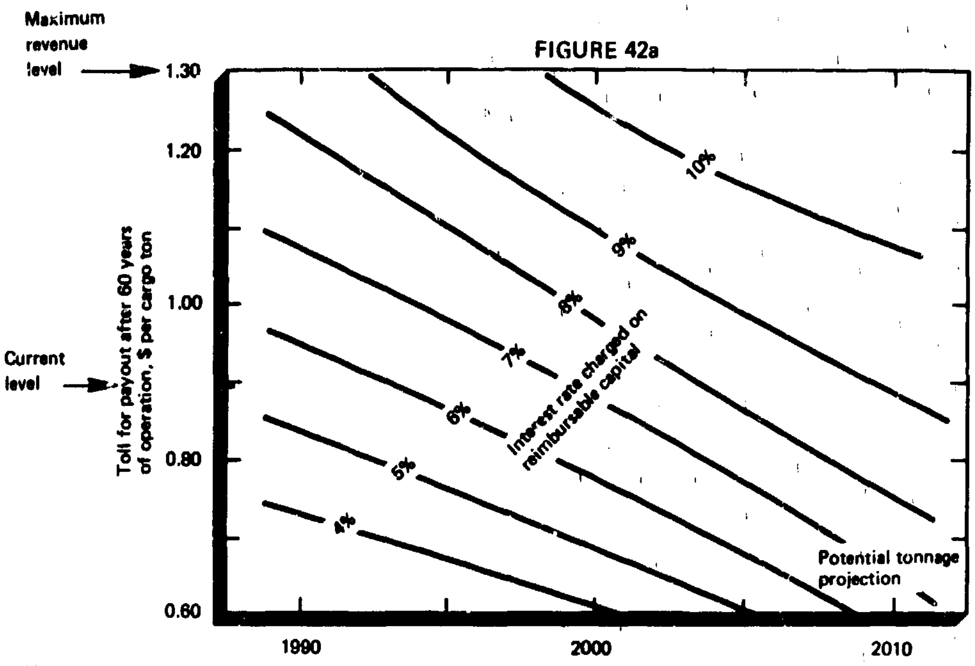
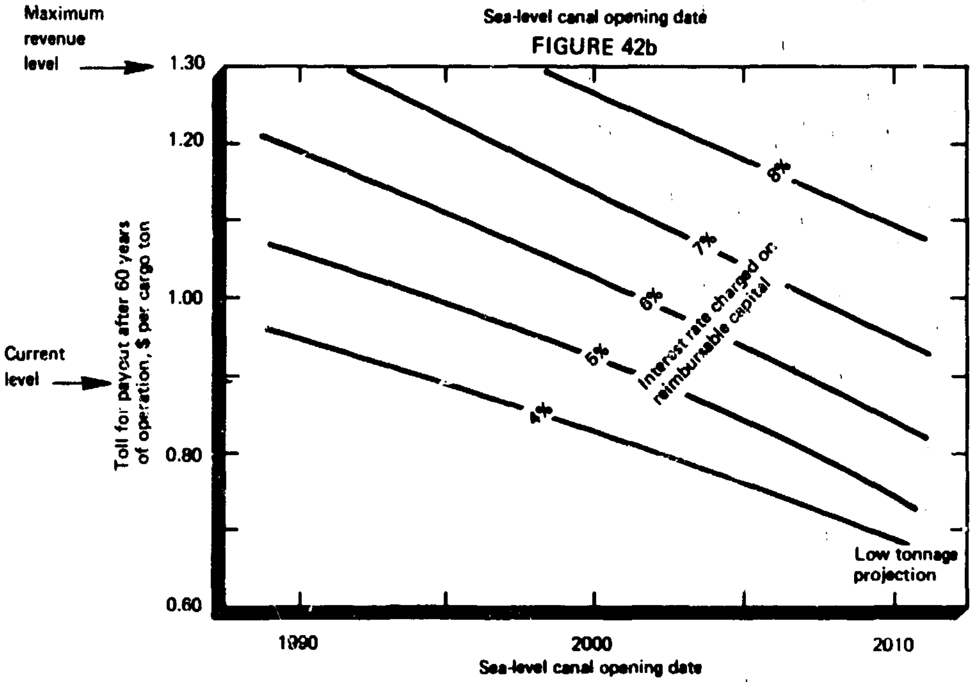


FIGURE 42b

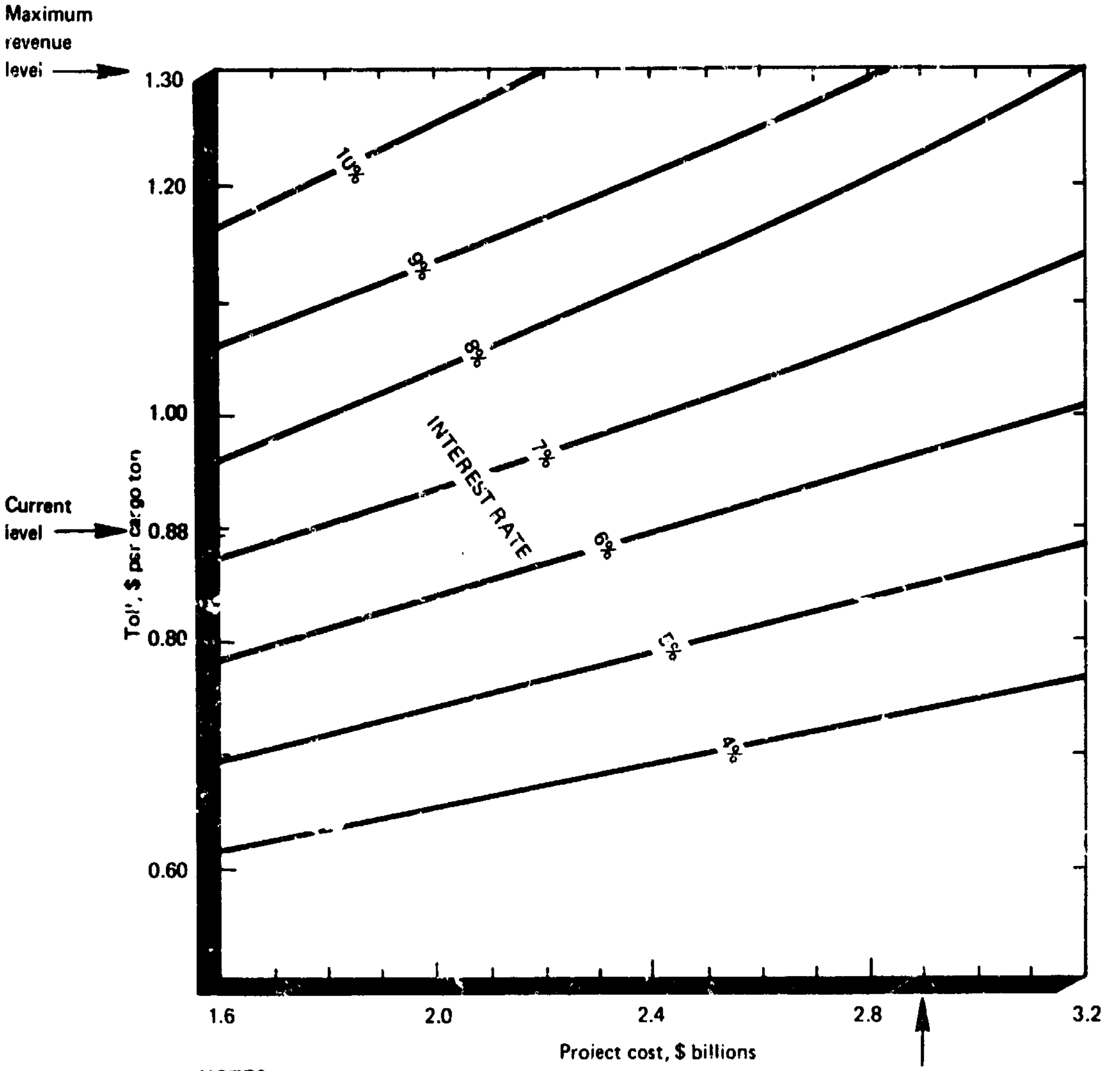


NOTES:

1. Canal financing assumed an extension of that of the Panama Canal with a 1970 debt of $317 million.
2. Toll of $0.884 per cargo ton assumed until canal construction is started.
3. Panama Canal assumed on standby for ten years, and then in mothballs.
4. Route 10 cost is $2.88 billion.
5. Royalty reaches $0.22 in 1976.

ROUTE 10 TOLL PER CARGO TON VS. CANAL OPENING DATE

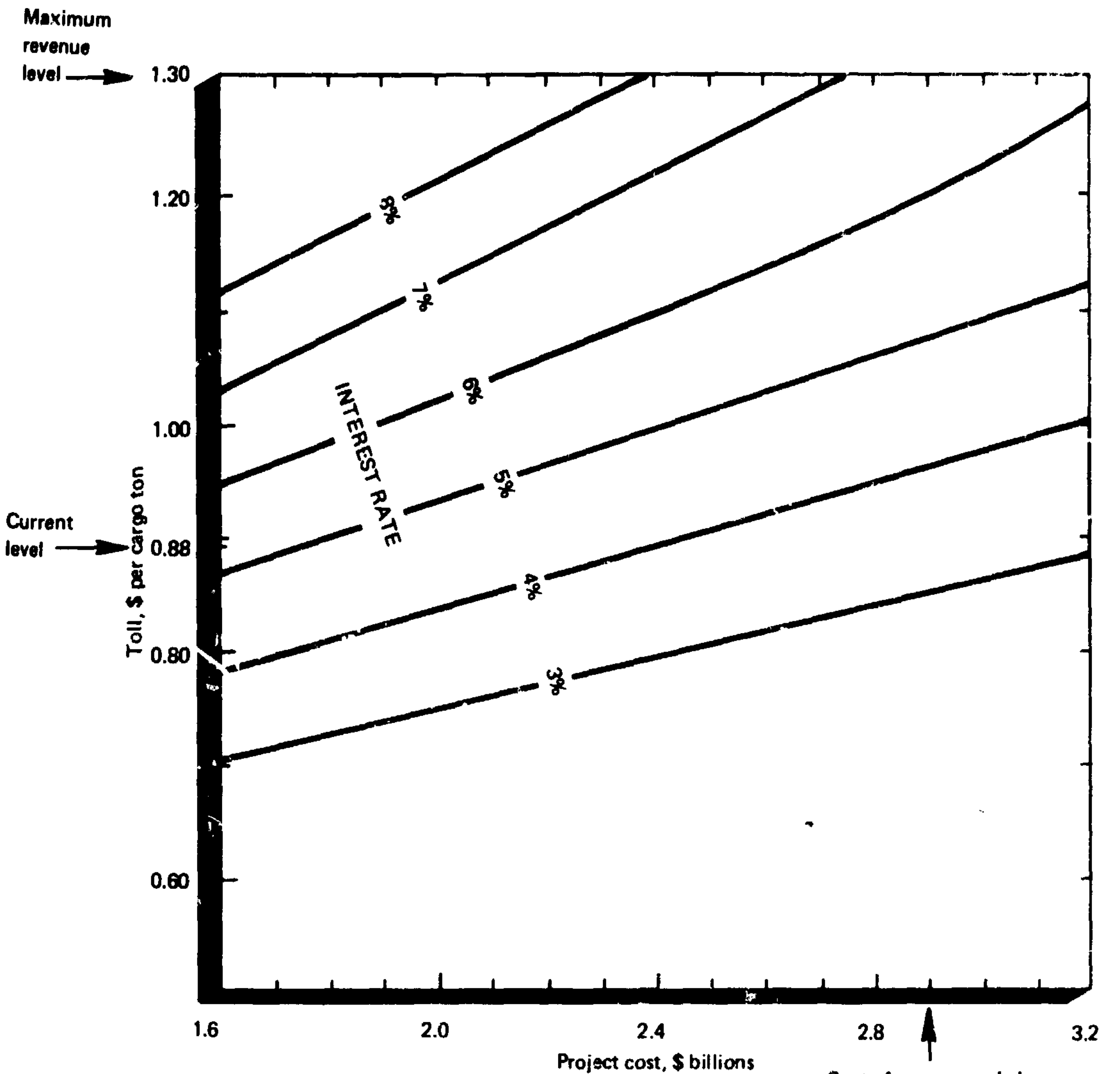
FIGURE 42



NOTES:

1. Route 10 construction schedule is assumed.
2. Royalty reaches $0.22 in 1976.
3. Sea-level canal opens in 1990.
4. Payout is in 2050.
5. Potential tonnage and 25% freighter cargo mix are assumed.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Tolls of $0.884 per cargo ton assumed until sea-level canal construction is started.
8. Panama Canal assumed on standby for ten years and then in mothballs.

ROUTE 10 SENSITIVITY OF TOLL TO PROJECT COST
FIGURE 43a



NOTES:

1 Route 10 construction schedule is assumed.
2. Royalty reaches $0.22 per cargo ton in 1976.
3. Sea-level canal is opened in 1990.
4. Payout is in 2050.
5. Low tonnage and 46% freighter cargo mix are assumed.
6. Canal financing assumed an extension of that of the Panama Canal with a 1970 debt of $317 million.
7. Toll of $0.884 per cargo ton assumed until sea-level canal construction is started.
8. Panama Canal assumed on standby for ten years and then in mothballs.

ROUTE 10 SENSITIVITY OF TOLL TO PROJECT COST
FIGURE 43b

TABLE 20

ESTIMATED PEAK DEBT AT 6 PER CENT FOR CONSTRUCTION OF SEA-LEVEL CANAL ON ROUTE 10 OPERATED IN CONJUNCTION WITH THE PANAMA CANAL

Average Toll Per Long Ton of Cargo	Low Traffic Growth Canal Opening Date 1990	Low Traffic Growth Canal Opening Date 1995	Low Traffic Growth Canal Opening Date 2000	Potential Traffic Canal Opening Date 1990	Potential Traffic Canal Opening Date 1995	Potential Traffic Canal Opening Date 2000
$0.80	Not Possible to Amortize Within					4.4
0.90	60 Years of Operation				4.9	3.3
1.00				5.2	3.6	2.7
1.10		3.6	2.6	3.9	3.1	2.2
1.20	3.6	2.7	2.2	3.3	2.7	1.6
1.30	2.8	2.3	1.7	2.9	2.2	1.1

Notes: Debt shown in billions of dollars.
Toll rates assumed effective 15 years ahead of opening date.
Initial construction cost: $2.88 billion.
Royalty payments at 22 cents per ton.
Operating costs per estimates in Annex V.

toll of $1.00 per cargo ton, interest at 6 per cent, and realization of potential traffic revenues, the tabulation shows that in the first 10 years the peak debt would be reduced an average of $250 million for each year of deferment beyond 1990.

Modified Premises

All of the calculations of requisite tolls in Table 19 and of the peak debt in Table 20 were based on two premises: payments to the host country would be 22 cents per cargo ton after 1975, and all of the capital costs would be amortized with interest within 60 years after the opening date of a new canal. Any modification of these would have an effect on the tolls that would have to be collected and on the magnitude of the peak debt that would accrue.

The royalty to be paid Panama could be at a different rate per cargo ton or the payments could be computed on a different basis. Hence, in preparation of Figure 44, the assumed amount of 22 cents per cargo ton has been eliminated in order to show the average toll that would produce the revenues needed to cover all costs of operation and to amortize the capital cost.

If a sea-level canal on Route 10 were built to open in 1990 and the potential traffic forecast were experienced, there would be full recovery of the $2.88 billion capital cost in

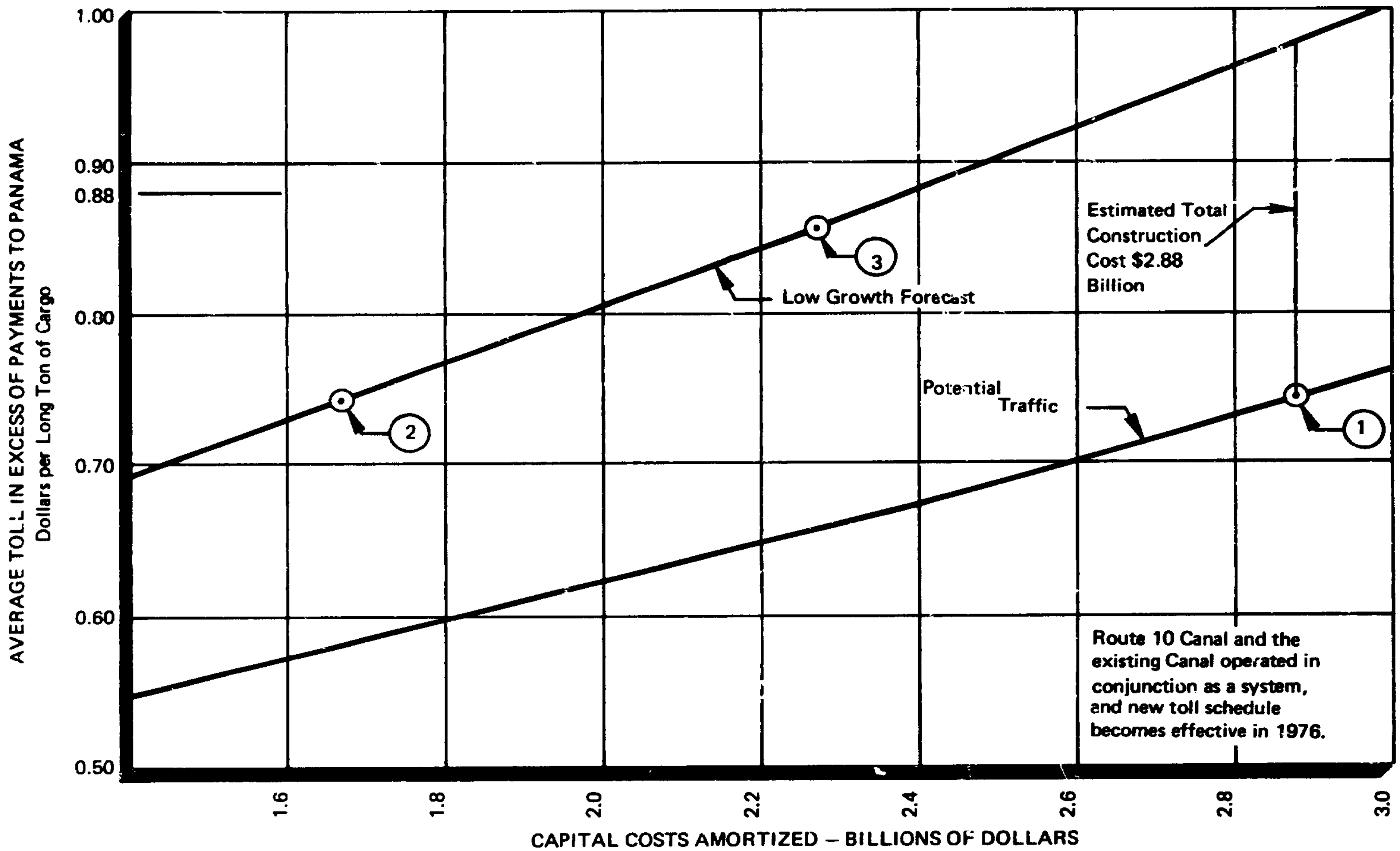
60 years at 6 per cent interest, provided tolls were raised at the start of construction (1975) to an average 96 cents per cargo ton (74 cents plus royalty payments to Panama of 22 cents per ton). (Point 1, Figure 44). On the other hand, should the traffic growth follow the low estimate of the Shipping Study Group only $1.67 billion of the capital cost could be amortized at the same toll rate. (Point 2, Figure 44). Under this condition, $1.21 billion of the capital cost could not be amortized. This is one measure of the degree of risk.

Amortization of all capital costs from toll revenues places all of the burden of amortization on canal users. There could be foreign policy or defense judgments that some of this burden should be shifted by Federal contributions in aid of construction. In the example just cited, this would amount to the write-off of $1.21 billion as non-reimbursable. If only one-half of this amount were deemed properly non-reimbursable, and if no higher level of tolls were practicable, amortization of the remaining capital cost ($2.28 billion) would require that the payment to Panama be approximately 10 cents per cargo ton (96 cents minus 86 cents, Point 3, Figure 44).

Thus, if a decision or a commitment were made to complete a sea-level canal on Route 10 in 1990, tolls would have to be raised under either traffic assumption to avoid capital write-offs, and substantially in the event the low traffic growth should be experienced. A start of operation in 1990 carries the attendant risk of the need to subsidize the construction with sizeable capital write-offs. Lesser payments to the host country, especially in the early years, would help to lessen the amount.

Source of Funds

It is apparent from the Study of Canal Finance, Annex III, that the risks and uncertainties of sea-level canal finance are such that private funding of construction costs would not be feasible. The Commission concluded that responsibility for construction and operation of a sea-level canal should be vested in an independent agency of the United States Government and that construction be financed through appropriations by the Congress. The financial burden on the United States might be reduced by international participation. The prospects of obtaining such participation are discussed in the following chapter.



Average Tolls in Addition to Payments to Panama Required for Amortization at 6 Per Cent of all or Part of the Capital Cost of Route 10 Canal if Completed in 1990

FIGURE 44

CHAPTER IX

MANAGEMENT OF SEA-LEVEL CANAL CONSTRUCTION AND OPERATION

During the past twenty-five years, especially in periods of difficult United States-Panamanian relations, prominent political leaders in the United States have suggested that the Panama Canal be internationalized or inter-Americanized. They have suggested that an international management authority would mitigate the anti-United States sentiment in Panama that stems from our unilateral control of the Canal Zone and all operations within it.

The Commission believes that international participation in the operation of the present lock canal and in the financing and operation of a new sea-level canal under new treaty arrangements mutually acceptable to the United States and Panama could eliminate many of the important obstacles to harmonious relations and thus facilitate long-term protection of the huge investment in the canal enterprise. In Latin America generally, such an arrangement could be welcomed as a move toward adjusting United States national interests to the cooperative goals of the inter-American system.

The cost of a new sea-level canal is so large and amortization of the debt is sufficiently problematic that it is in the interest of the United States to obtain international financial support for the enterprise. Prospects for attaining the cooperation of a substantial number of canal users are not bright, however. An Isthmian canal is of marginal importance to the larger nations that now use the canal, with the possible exception of Japan. If additional canal capacity were not provided in the future, all could use alternate routes. Since they no doubt believe that the predominant United States economic and military interests are such that an adequate Isthmian crossing will be built and maintained without their participation, they are likely to conclude that they can avoid financial and management responsibilities, as well as the foreign policy problems that might arise from time to time. The Pacific Coast nations of South and Central America, while greatly dependent on an efficient Isthmian crossing, are not in a position to make significant contributions to canal construction.

Panama has historically resisted multi-national participation. Despite the discouraging obstacles, however, internationalization should continue to be a goal of the United States, but not an inflexible condition of our canal policy.

Management of Construction

Useful lessons can be drawn from the mistakes and successes of the three successive Isthmian Canal Commissions appointed between 1904 and 1914 to build the present canal. The management problems that initially plagued the builders of the Panama Canal stemmed in part from lack of clear lines of authority between the President, the Commission, the Chief Engineer, and the operating forces on the Isthmus. Operations were handicapped by slow communications between the Commission in the United States and the operating forces in Panama and the Commission's failure to delegate to its Chief Engineer the power

of decision on relatively small matters. The final and effective solution adopted by President Theodore Roosevelt was to appoint the same individual to the positions of Commission Chairman and Chief Engineer.

There was also controversy over the merits of government-force construction versus construction by private contractors. The Chairman/Chief Engineer, John F. Stevens, created an effective construction force and saw no need to execute the project through contractors as desired by the President. His resignation before this issue was resolved led to the appointment of Colonel George Washington Goethals of the United States Army Engineers as Chairman and Chief Engineer. Colonel Goethals, however, found Stevens' organization thoroughly satisfactory and executed his plans relatively unchanged without resort to contracting. Although Goethals and a number of his key subordinates were Army Engineers, the organization that built the Panama Canal remained to the end an autonomous civilian agency of the Executive. Responsibility for its supervision at the Washington level was delegated to the Secretary of War. Although never required by legislation, this practice continues today in the operation of the Panama Canal.

Advances in the fields of engineering, sanitation, transportation, and communications since Stevens and Goethals' time make canal building a different problem today. Private construction contractors, separately or as joint ventures, now have the capabilities to build very large projects. United States Government construction agencies have demonstrated in peace and war the ability to manage large construction projects anywhere in the world. The speed of modern transportation and communications makes insignificant the distance between Washington and the Isthmus.

The major factors to be considered are:

- The construction agency would function over a period of 15 years or longer.
- The primary functions of the agency would be engineering design, management of construction, and at the national level, coordination of the interests of all government agencies concerned.
- Some form of host-country participation in the management agency seems essential. Any construction of the magnitude of a sea-level canal could have major impacts on the economy of the host country and on its relations with the United States. Multi-national financing of construction, if undertaken, would entail further obligations for international participation.
- Regardless of the management scheme employed, it is essential that flexibility be allowed for the award of construction contracts for major units of the work.
- The construction agency should have the exemptions from taxation, import duties, and employment restrictions needed to conduct its activities with the maximum efficiency and at the minimum cost to the United States.

In the absence of major contributions by other nations in financing sea-level canal construction, it is obvious that construction could be financed only by the United States Government. In this event, it would be essential that construction be managed by an agency of the Executive subject to the appropriation processes of the Congress. The logical choices of management agencies for sea-level canal construction are two:

- An autonomous agency such as was used for the first canal.
- The Department of the Army, working through the United States Army Corps of Engineers.

An autonomous agency with no other mission would be preferable. The canal project would be only one of many for the Corps of Engineers.

The national and international interests in a sea-level Isthmian canal are such that no single United States Government department or other national agency has a dominant interest. An autonomous agency would be the most practical arrangement for bringing together the skills needed for the direction of so great a project without assigning disproportionate responsibilities to an existing agency with other important missions to perform. It would facilitate the participation of private citizens and would lend itself to foreign participation, if desired. The exact membership of the directing authority at the national level would be influenced by the treaty terms and financial arrangements finally agreed upon for a new canal. Its membership should be limited in number with provision for advisory participation by representatives of the Departments of Defense and State, the host country government, and the operating authority of the present canal.

Management of Canal Operations

The management organization for operation of a sea-level canal in Panama, either alone or as part of a canal system that included the existing canal, would inevitably evolve from the existing canal operating authority. The Commission did not develop recommendations for the organization of this new authority. Its responsibilities, functions, and methods of operation will depend upon treaty arrangements yet to be negotiated and, thereafter, on a choice of alternatives.

Advance Planning

The feasibility of constructing a sea-level Isthmian canal by the United States alone or in cooperation with other nations cannot be finally determined in the absence of agreement on treaties for both the old and new canals. Without a suitable treaty insuring the continued protection of its interests, the United States cannot undertake construction of a new canal or underwrite its construction. Without a treaty, there is no basis upon which the President can propose canal construction legislation to the Congress.

Pending the establishment of suitable treaty conditions, planning for the management of construction and operation of a new canal should be temporarily deferred. The earliest date that greater canal capacity might be needed is approximately 1990, and need at that date is not expected to be critical. With a planning and construction lead time of 15 years, the earliest date at which decision might be needed is 1975. If canal traffic continues to grow as forecast, and if suitable treaty arrangements have been negotiated and ratified, the President should at that time, or as soon thereafter as he deems appropriate, consider proposing sea-level canal construction legislation to the Congress.

CHAPTER X

CONCLUSIONS AND RECOMMENDATIONS

A sea-level canal across the American Isthmus has been sought for more than four centuries, and all who have participated – the Spanish, the French, and the American builders of the present lock canal – remained convinced that a sea-level canal ultimately should be constructed. The canal studies in 1947, 1960, and 1964 arrived at the same conclusion but counseled interim measures and postponement of construction.

Today there are no technical obstacles of sufficient magnitude to prevent successful construction and operation of a sea-level canal. Determination of its feasibility must be a judgment of values, many of which are unquantifiable. The political, economic, and military advantages for the United States, the Western Hemisphere, and the world in an adequate and secure Isthmian canal cannot be measured precisely. A weighing of estimated costs against estimated revenue is only one measure, and a tenuous one at best. The most critical elements – the treaty arrangements for canal construction, operation, and defense – remain to be established. Nevertheless, the Commission believes that the essential treaty conditions are apparent, and on the basis of the many considerations discussed in this report and its annexes, it has reached the following conclusions and recommendations:

Conclusions

1. The United States, as the major Western Hemisphere power has the responsibility of insuring the continued availability of an adequate and secure Isthmian canal operated on a neutral and equitable basis. This obligation is recognized in United States treaty agreements with the United Kingdom, Panama, and Colombia.
2. The Panama Canal is of major importance to the defense of the United States. The United States should retain an absolute right to defend the present canal and any new Isthmian canal system for the foreseeable future.
3. An adequate Isthmian canal is of great economic value to many nations, but especially to the United States since approximately 70 per cent of the tonnage through the canal in recent years has been to, from, or between United States ports. This relationship is expected to continue.
4. The size limitations of the existing Panama Canal impose constraints upon the use of bulk carriers on canal routes. The worldwide trend to larger ships for movements of bulk commodities will make these constraints of increasing economic significance to United States and world trade as time passes.
5. The potential demand for annual transits of ships of the size that can pass through the present canal probably will exceed its estimated maximum capacity of 26,800 annual transits during the last decade of this century. Saturation of the existing canal will impose difficult but not necessarily intolerable constraints on world shipping. If greater canal capacity for both numbers of transits and larger ships is not provided, potential traffic increasingly will be diverted to larger ships on

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alternate routes and to other transportation modes. Provision of additional canal capacity would be advantageous to the continued growth of United States and world trade.

6. Initial construction of additional canal capacity should provide for handling ships up to 150,000 DWT. New locks designed for such ships would have no greater size capacity, but a sea-level canal that could accommodate 150,000 DWT ships routinely could accommodate 250,000 DWT ships under controlled conditions.
7. The new capacity that should be provided initially is 35,000 annual transits. Any plan adopted should not preclude progressive expansion to double or even triple this capacity.
8. A total canal capacity of at least 35,000 annual transits could be provided by constructing a third lane of locks for the present canal. This would be a temporary solution without significant military advantages, and it would not relieve the problems in United States-Panamanian relations that derive from the personnel and defense requirements of the lock canal. The augmented capacity could be exceeded by demand for transits soon after the new locks were built. Locks capable of accommodating ships of 150,000 DWT would cost more than three-fifths as much as a sea-level canal of far greater capacity and would not be capable of transiting the Navy's angle-deck aircraft carriers. Additional locks would also increase the operating costs of the canal far above those of a sea-level canal.
9. A sea-level canal would provide a significant improvement in the ability of an Isthmian waterway to support military operations both in its lessened vulnerability to interruption by hostile action and in its ability to transit large aircraft carriers that cannot now pass through the Panama Canal. These military advantages of a sea-level canal, together with its capacity to meet the potential demand for transits over a much longer period, and its lesser operating costs, would more than counter-balance the lower construction cost of augmenting the existing canal with larger locks.
10. The technical feasibility of the use of nuclear explosives for sea-level canal excavation has not been established. Whether the technology can be perfected and the international treaty obstacles to its use removed are not now predictable. Removal of the technical and treaty obstacles to employment of nuclear excavation would still leave major political and economic obstacles to a sea-level canal remote from Panama's population centers. A sea-level canal on Route 17, excavated wholly or in part by nuclear explosions, is currently infeasible for manifold reasons and probably will remain so, regardless of the establishment of technical feasibility of nuclear excavation. A sea-level canal excavated partially by nuclear methods on Route 25 in Colombia might someday be politically acceptable if proved technically feasible.
11. A sea-level canal in Panama constructed by conventional excavation either on Route 10 or Route 14 is technically feasible.
12. Route 10 is the most advantageous sea-level canal route
13. Although available evidence indicates that the tidal currents expected in a sea-level canal without tidal control structures could be navigated safely by most ships, tidal gates could increase navigation safety and should be provided.

14. A conventionally excavated sea-level canal on Route 1(idal gates, capable of accommodating at least 35,000 transits each year of rep ative mixes of ships of the world fleet up to 150,000 DWT, would cost $2.88 billion to construct at 1970 prices.
15. The costs and revenues of a future sea-level canal cannot be forecast reliably over the 75-year period that might be needed for its construction and amortization. Among the critical factors are the cost of money and the stability of the value of money. If the old and new canals were financially integrated at initiation of new construction, and if the most favorable forecast developments in construction costs, revenues, and interest rates were realized, a sea-level canal opening in 1990 could be financed through tolls while paying reasonable royalties to Panama. Less favorable developments in future costs and revenues which are possible during the period would make amortization through tolls impracticable. Amortization could require toll increases over the present Panama Canal levels as well as additional periodic increases to compensate for inflation of future costs. Low interest rates or low royalties would facilitate financing larger investments and permit lower tolls. Conversely, high interest rates, high royalties, or tolls lower than economically justified would reduce the construction investment that might be amortized from tolls.
16. A variable pricing system for tolls designed to meet the competition of alternatives to the canal would attract the most traffic and generate the greatest revenues in a future canal of any type, lock or sea-level.
17. Assurance of recovery of the United States investment is desirable, but need not be the sole determinant of United States canal policy. The decision to build or not to build a sea-level canal should also take into account economic, political, and military factors.
18. Although true internationalization of a future sea-level Isthmian canal does not appear to be attainable, multi-national participation in its financing and management could be financially and politically advantageous. The United States should seek such participation within a bi-national treaty with Panama, but not make future United States canal policy dependent upon its attainment.
19. United States relations with Panama could be improved by progressive reduction of the number of United States personnel in the canal operating authority and a concomitant increase in the proportion of Panamanian personnel in the positions normally occupied by United States citizens. Construction of a sea-level canal would facilitate reduction of the United States presence in that it could be operated and defended with fewer total personnel.
20. Construction of a sea-level canal on Route 10 or Route 14 would create great economic benefits for Panama. Of the alternatives considered, the greatest benefits in added employment and foreign exchange earnings for Panama would be derived from construction of a sea-level canal on Route 10 and operating it together with the existing canal as a single system.
21. United States canal objectives and enduring tranquil relations with Panama are most likely of attainment under a treaty arrangement which gives Panama a greater role in the canal enterprise than at present and justifiable economic benefits from

canal activities, but the United States should retain effective control of canal operations.

22. So far as the Commission is able to determine on the basis of limited studies, linking the oceans at sea-level would not endanger commercial or sport fish on either side of the American Isthmus. No significant physical changes to the environment appear probable outside the immediate areas of excavation and spoil disposal. Tidal gates could be used to eliminate substantially the flow of water between the oceans, and the water between the gates would have incidental temperature and salinity differences from either ocean that would constitute a limited barrier to transfer of marine life. A definitive and reliable prediction of all ecological effects of a sea-level canal is not possible. The potential for transfer of harmful biota and hybridization or displacement of species in both oceans exists but the risks involved appear to be acceptable. Long-term studies starting before construction is initiated and continuing many years beyond the opening of a sea-level canal would be required to measure ecological effects.
23. A decision to construct a sea-level canal should allow for planning and construction lead time of approximately 15 years to meet the projected date of need, which can be fixed with increasing confidence as it draws nearer. Other factors, however, including the treaty terms with Panama that are ultimately negotiated and ratified, as well as the national priorities for Federal financing then existing, should be the final determinants of whether the President should propose sea-level canal legislation to the Congress.
24. Construction of a sea-level canal, if financed principally by the United States, should be planned and carried out under the direction of an autonomous authority of the United States Government.

Recommendations

The Atlantic-Pacific Interoceanic Canal Study Commission* recommends that:

1. Any new canal treaty arrangement with the Republic of Panama provide for:
   a. Creation of an Isthmian canal system including both the existing Panama Canal and a sea-level canal on Route 10, operated and defended in an equitable and mutually acceptable relationship between the United States and Panama.
   b. Canal operating and defense areas that include both the existing Panama Canal and Route 10.
   c. Effective control of canal operations and right of defense of the canal system and canal areas by the United States, with such provisions for Panamanian participation as are determined by negotiation to be mutually acceptable and consistent with other recommendations herein.
   d. Acquisition of the Route 10 right-of-way by the canal system operating authority as soon as practicable.

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*Chairman Robert B. Anderson, because he is also Special Representative of the United States for United States-Panama Relations, disassociated himself from Recommendation 1, which concerns new treaty arrangements with the Government of Panama.

2. The canal system be operated to provide an equitable share of revenues and other economic benefits for Panama consistent with efficiency of canal operations, financial health of the enterprise, and maintenance of toll levels that permit effective competition with alternatives to the canal.
3. Other nations be encouraged to participate in financing the canal system, if such multi-national participation is acceptable to the Government of Panama.
4. Subject to the priority of more important national requirements at the time, the United States initiate construction of a sea-level canal on Route 10 no later than 15 years in advance of the estimated saturation date of the present canal, now projected to occur during the last decade of this century.
5. When the rights and obligations of the United States under new treaties with Panama are established, the President reevaluate the need for and desirability of additional canal capacity in the light of canal traffic and other developments subsequent to 1970, and take such further steps in planning the construction of a sea-level canal on Route 10 as are then deemed appropriate.
6. Modernization of the existing canal to provide its maximum potential transit capacity be accomplished, but no additional locks be constructed.
7. The United States pursue development of the nuclear excavation technology, but not postpone Isthmian canal policy decisions because of the possible establishment of feasibility of nuclear excavation at some later date.
8. The following studies initiated in the course of the Commission's investigation, if not otherwise completed beforehand, be continued to completion by the control authority of the new canal system if such an authority is established and the Route 10 right-of-way acquired:
   a. Investigation of the subsurface geology of the proposed trace of Route 10 to permit selection of the exact alinement for design purposes.
   b. Investigation of slope stability applicable to Route 10 geologic conditions.
   c. Investigation into the hydrodynamics of large ships moving through confined waters with variable currents.
9. A permanent agency of the Executive be designated to support and coordinate public and private research activities that could contribute to the evaluation of the potential environmental effects of a sea-level canal, and if the decision is made to initiate its construction, advise the President as to the organization for and funding of such additional research as might be required to reach definitive conclusions.

ENCLOSURE 1

COMMISSION AUTHORIZING LEGISLATION

ENCLOSURE 1

COMMISSION AUTHORIZING LEGISLATION

Public Law 88-609, 88th Congress, S. 2701, September 22, 1964, 78 Stat. 990, as amended by: Public Law 89-453, 89th Congress, S. 2469, June 17, 1965, 80 Stat. 203; Public Law 90-244, 90th Congress, S. 1566, January 2, 1968, 81 Stat. 781; and, Public Law 90-359, 90th Congress, H.R. 15190, June 22, 1968, 82 Stat. 249:

AN ACT

To provide for an investigation and study to determine a site for the construction of a sea level canal connecting the Atlantic and Pacific Oceans.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the President is authorized to appoint a Commission to be composed of five men from private life, to make a full and complete investigation and study, including necessary on-site surveys, and considering national defense, foreign relations, intercoastal shipping, interoceanic shipping, and such other matters as they may determine to be important, for the purpose of determining the feasibility of, and the most suitable site for, the construction of a sea level canal connecting the Atlantic and Pacific Oceans; the best means of constructing such a canal, whether by conventional or nuclear excavation, and the estimated cost thereof. The President shall designate as Chairman one of the members of the Commission.

Sec. 2. (a) In order to carry out the purposes of this Act, the Commission may—

(1) utilize the facilities of any department, agency or instrumentality of the executive branch of the United States Government;

(2) employ services as authorized by section 15 of the Act of August 2, 1946 (5 U.S.C. 55a), at rates for individuals not in excess of $100 per diem;

(b) The members of the Commission, including the Chairman, shall receive compensation at the rate of $100 per diem. The members of the Commission, including the Chairman, shall receive travel expenses as authorized by law (5 U.S.C. 73b-2) for persons employed intermittently.

Sec. 3. The Commission shall report to the President for transmittal to Congress on July 31, 1965, with respect to its progress, and each year thereafter until the completion of its duties. The President shall submit such recommendations to the Congress as he deems advisable. The Commission shall continue until the President determines that its duties are completed, but not later than December 1, 1970.

Sec. 4. There are hereby authorized to be appropriated without fiscal year limitation such amounts as may be necessary to carry out the provisions of this act, not to exceed $24,000,000.

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ENCLOSURE 2

REPORT OF THE TECHNICAL ASSOCIATES FOR GEOLOGY, SLOPE STABILITY AND FOUNDATIONS

TECHNICAL ASSOCIATES FOR GEOLOGY, SLOPE STABILITY AND FOUNDATIONS OF THE ATLANTIC-PACIFIC INTEROCEANIC CANAL STUDY COMMISSION

CONSULTING GEOLOGISTS	CONSULTING ENGINEERS
FRANK A. NICKELL – San Mateo, Calif.	ARTHUR CASAGRANDE – Cambridge, Mass.
ROGER RHOADES – San Francisco, Calif.	PHILIP C. RUTLEDGE – New York, N.Y.
THOMAS F. THOMPSON – Reno, Nevada	

March 2, 1970

Mr. Robert B. Anderson, Chairman
Atlantic-Pacific Interoceanic Canal Study Commission
726 Jackson Place, N.W.
Washington, D.C. 20506

RE: COMPARISONS OF INTEROCEANIC CANAL ROUTES

Dear Mr. Chairman:

The scope and organization of the following report result from discussions during the meeting with Commissioners Hill and Fields in San Francisco on January 28 and 29, 1970. It consists of two main sections, one concerned with Routes 17 and 25 that require nuclear excavation and the other with Routes 10, 14C and 14S that would be constructed wholly by conventional excavation. The concepts and conclusions have evolved from association with the investigation since its beginning in 1965 and from continuous review of the extensive investigations and reports of the Corps of Engineers' study groups. Detailed technical recommendations, which were reported to the Corps of Engineers periodically during the study, are not repeated herein.

The comparisons between routes have been based on considerations of geology and engineering related to design and construction of a canal, in light of the existing state of knowledge of effects on slope stability, to result in an evaluation of the relative merits, disadvantages, uncertainties and risks of routes for a sea-level interoceanic canal. In the first main section Routes 17 and 25 are compared assuming feasibility of nuclear excavation and the feasibility assumption is then considered. In the second section comparisons of conventional excavation routes are made between Route 10 and Routes 14C and 14S and then between the latter two routes within the Canal Zone.

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ROUTES REQUIRING NUCLEAR EXCAVATION OVER PORTIONS OF THEIR LENGTH

Routes 17 and 25 require nuclear excavation of very deep cuts through the mountainous sections to make them economically feasible. These routes are first compared in their entirety and then the feasibility of nuclear excavation for canal construction is discussed. Assuming that nuclear excavation is feasible, comparison of Routes 17 and 25 logically divides itself into the mountainous sections requiring nuclear excavation, the lower-lying sections excavated by conventional methods, and requirements for diversion of flood waters.

(1) Mountainous Sections

The continental divide on Route 17 is near the Atlantic side and is near the Pacific on Route 25. The highest elevations are roughly the same but the length of high elevation for Route 25 is somewhat less. The geology and basic types of rocks are similar and will permit relatively steep excavation slopes such as might be produced by nuclear blasting.

On Route 25 it seems possible for reasons of geology that nuclear excavation could be extended farther to the east than shown on the construction plan, thereby reducing the requirement for more costly conventional excavation.

On Route 17 there is a second high ground section near the Pacific entrance. This presents two distinct disadvantages; first, the geologic structure of the Pacific highland is more complicated than in the continental divide and the rocks are less competent, creating some uncertainty as to stability of slopes produced by nuclear excavation; and second, the two separated sections requiring nuclear excavation doubles the number of interfaces with conventional excavation sections. Such interfaces and transition zones between the two types of excavation introduce uncertainties into design and construction. Design problems include: (1) the selection of the points where the transition can safely be made, and (2) determination of stable slopes for the transitions. Construction problems exist in extending conventional excavation into the deep masses of broken rock created by larger nuclear explosions.

In balance, the problems of nuclear excavation are less on Route 25 and this route is the more favorable for nuclear construction if and when feasibility of the method can be established.

(2) Conventional Excavation Sections

Route 17 includes a length of about twenty miles across the Chucunaque Valley where the average ground surface is about Elev. 200. The underlying rocks are clay shales of the Sabana beds in which the possibility of creating stable slopes by nuclear excavation procedures is very unlikely. In fact, proper slopes for conventional excavation would have to be developed for these weak rocks and some trial excavations would be required to establish economical safe slopes. In addition, it is not yet known how far the weaker rocks of formations bordering the Sabana Beds extend into the foothills of the Atlantic and Pacific

divide sections but geologically it seems possible that conventional excavation might have to extend into relatively high ground, further increasing difficulties and costs.

In comparison, Route 25 has a length of eighty miles across the Atrato Swamps but the surface elevation for most of this length is close to sea level. Generally, the materials for the full depth of the canal prism are soft organic deposits and unconsolidated soils which can be removed by hydraulic dredging. Techniques for building a canal in such materials are well established, no unprecedented methods are required, and no significant difficulties are anticipated. It would also be easy to widen or to divide the canal into separate channels in this section if sufficient space is left between protective levees in the initial planning.

In summary, the greater length of conventional excavation on Route 25 is more than offset by absence of grave uncertainties in design and construction as compared with Route 17.

(3) Flood Diversion Requirements

Route 25 has the disadvantage of large volume rivers with heavy silt loads flowing toward the alignment in its lower reaches. These flows would create unacceptable conditions in the sea-level canal; large and long flood diversion channels are required on both sides of the canal to carry the flood waters to safe discharge into the Atlantic, particularly on the east side where the flood channel for the Atrato River approaches the size of the canal itself. The penalty lies in volume of required excavation and cost, but no particular design and construction difficulties are anticipated.

Head water river flows on Route 25 will enter the canal but the volumes of flow are small and no particular difficulties are anticipated. On Route 17 it is planned to drop the flows of the Sabana and Chucunaque Rivers into the canal. The flood flows here are somewhat larger than the head water river flows into Route 25 and the silt load is expected definitely to be larger, creating a requirement for maintenance dredging in the Route 17 channel. No particular difficulties are anticipated in developing a design for safe dissipation of energy where the waters of these rivers are dropped into the canal.

Feasibility of Nuclear Excavation

Feasibility of excavation by nuclear explosions is discussed in terms of: (1) the present situation, i.e. the possibility of its being used with assurance for interoceanic canal construction within the next ten years; (2) the requirements for a continuing program of nuclear testing to assure future feasibility; and (3) the possibilities of future applicability to weak rocks such as the clay shales of the Chucunaque Valley. These discussions apply exclusively to the physical development and configuration of craters which would result in a usable canal and exclude all other effects of nuclear explosions such as seismic, air blast, and radiological hazards.

(1) Present Feasibility

The Technical Associates are in unanimous agreement that the techniques for nuclear excavation of an interoceanic canal cannot be developed for any construction that would be planned to begin within the next ten years.

The reasons for this opinion are:

a. Extension of the scaling relations now established by tests to the much higher yield explosions is too indefinite for assured design and the "enhancement" effects due to saturated rocks and row charge effects now assumed have not been proved by large scale tests. There is a definite possibility of a major change in the mechanics and shape of the crater formed by the much higher yield explosions required for the canal excavations as compared to extrapolations from the relatively small-scale tests carried out to date.

b. The effects of the strength of rock on the stability of "fall-back" slopes and the broken rock crater slopes projecting above the fall-back to the great heights required for an interoceanic canal have not yet been established.

Therefore, the Technical Associates conclude that nuclear excavation cannot safely be considered as a technique for assured construction of an interoceanic canal in the near future.

(2) **Future Development**

The economic advantages of nuclear explosions for excavation of the very deep cuts required by an interoceanic canal are so great that the present "Plowshare" program should be continued, extended, and pursued vigorously until definitive answers are obtained. Assured application of this technology to design and construction of an interoceanic canal will require an orderly progression of tests up to full prototype size, including full-scale row charge tests, in generally comparable rock types, terrain and environment. Such a program may well require another ten to twenty years to establish whether or not nuclear excavation technology can be used with positive assurance of success for construction of a canal along Routes 17 or 25.

(3) **Application to Excavation in Clay Shales**

A growing body of knowledge and experience indicates that high slopes in clay shales, as in the Chucunaque Valley, or in more competent rocks underlaid by clay shales, as in parts of the existing canal, may have to be very flat for long-term stability and to avoid the danger of massive slides in the first few years after excavation. Some attempts have been made to produce such flat slopes by elaborate explosive techniques, such as over-excavation in anticipation of slides, multiple row charges, and successive series of explosions or "nibbling" techniques for application to problems such as construction of a sea-level canal across the Chucunaque Valley. The Technical Associates believe this to be a highly unpromising line of investigation with minimal chances of developing procedures that could be used with assurance in the foreseeable future.

ROUTES CONSTRUCTED BY CONVENTIONAL EXCAVATION

Routes which would be constructed wholly by conventional methods are Route 10 about ten miles to the west of the existing canal and generally outside of the Canal Zone

and Routes 14 Combined and 14 Separate both in the Canal Zone and near the existing canal. The relative advantages, disadvantages, risks and uncertainties will be discussed first as between Route 10 and either of the Routes 14 and second as between Route 14C and Route 14S.

Experiences with slides in the excavated slopes of the existing canal near the continental divide clearly demonstrate that achieving reasonably permanent slope stability is a major problem and would be a large economic factor in the design and construction on any of these routes. Comparisons herein are based primarily on uncertainties and risks of instability of excavated slopes, with some attention to the stability of structures and excavation spoil placed on top of the soft Atlantic mucks of the Gatun Lake area. All comparisons relate to the alignments and excavation slopes presented in the final reports prepared by the Corps of Engineers' study groups operating under the supervision of the Engineering Agent. It is recognized that some of the risks discussed herein have been partially compensated for by adoption of different slope design criteria for the three routes, as earlier recommended by the Technical Associates. The following discussion pertains to remaining advantages, disadvantages, uncertainties and risks.

Comparison of Route 10 with Routes 14C and 14S

Route 10 has the following advantages: (a) it could be constructed and placed in operation without hazard to or interferences with the existing lock canal which could be maintained on a standby basis. A slide during construction or in the first few years of operation, while undesirable, would not result in complete blockage of trans-isthmus ship passages as it would on Route 14C or 14S. (b) A large part of Gatun Lake could be maintained permanently at its present elevation by barrier dams, which would not be particularly difficult to construct where Route 10 crosses the lake. (c) By virtue of its separation from the existing canal and Gatun Lake, a large part of the excavation could be accomplished in the dry by well-established construction methods. (d) Large portions of the tremendous volume of excavation spoil could be transported to the Pacific and Atlantic Oceans for useful construction of breakwaters and for disposal with the least effect on the environment. (e) The terrain lends itself well to economical construction of a ship by-pass channel near the middle third of the length, if increases in traffic should make this necessary. This is not possible on Route 14.

A major disadvantage and uncertainty of Route 10 along the alignment presently explored is that about eight miles of the length across the continental divide, the highest and largest excavation volume part of the route, appears to be underlain by soft altered volcanic rocks at depths which would have major unfavorable effects on stability of excavation slopes. There is no precedent of excavation experience for the slope stability characteristics of these soft altered volcanics but results of laboratory testing indicate that they may be at least as weak as the clay shales which have caused severe slope instability along the existing canal. Thus, relatively flat excavation slopes have had to be assumed, even when adopting an "observational approach" in which trial slopes would be excavated and observed as full-scale tests to determine the steepest safe slopes.

The critical geology and structure of the underlying formations on Route 10 is completely masked by a thick basalt capping across the divide area. It must be assumed,

however, that similar structures and faulting as along the existing canal underlie the basalt. Some geologic evidence indicates that lateral shifting of the alignment of the reach through the continental divide, perhaps by a mile or so, might encounter more competent underlying rocks. If so, the disadvantage of higher terrain might be more than compensated for by use of steeper slopes, thereby reducing both excavation volumes and uncertainties. Therefore, design studies for Route 10 should include explorations of offset alignments in search of the best rock and geologic structure. This will require a very large number of core holes to depict the geologic conditions adequately for reasonable design and will necessitate one or more years' lead time for accomplishment of these required investigations. It is the geological consensus, however, that design explorations will not disclose subsurface conditions that are worse than those along the line now explored and which are reflected in use of conservative soft rock slopes for the entire eight mile length.

Routes 14C and 14S have the advantages of more extensive and complete subsurface and surface geological explorations in the area of the existing canal and of smaller excavation volumes due to the generally lower topography. An exception is the crossing of Gatun Lake at its widest point where barrier dams to establish differences in water levels may require large excavations and massive quantities of fill. Their disadvantages are almost certain interferences with operations of the existing canal during construction, complete loss of the existing canal during and after conversion to a sea-level canal, and loss of Gatun Lake in its present form. There are also uncertainties and risks of major slides which are discussed more fully in the comparison between Routes 14C and 14S.

Comparison of Route 14C with Route 14S

(1) Slope Stability

In the continental divide section, Route 14C involves hazards of major slides which could close the existing canal for long periods of time during construction of the new canal, and which thereafter could block the sea-level canal. These hazards result from much deeper excavations through sections where landslides have already been activated by construction of the existing canal. They would be particularly serious during the period of rapid drawdown required for conversion to a sea-level canal. While allowances for this hazard have been made in recommendations for slope design, there still remain unknowns and uncertainties concerning the effects of the rapid drawdown (in a period of about ten days) on the stability of slopes where past sliding and stress readjustment have created major planes of weakness.

Gold Hill presents a particular hazard to Route 14C. Observational records indicate that this rock mass is moving erratically and is squeezing softer materials below its base upward into the existing canal. It is believed that safe construction of Route 14C would require unloading of Gold Hill which will significantly increase the volume of excavation.

By virtue of its separation through the critical divide cut length, the hazard of slides blocking the existing canal are much less for Route 14S. It is possible that its excavation could still endanger the stability of Gold Hill but both the hazard and magnitude of any corrective unloading would be greatly reduced.

(2) Excavation and Excavation Spoil

Due to its location contiguous to the existing canal, Route 14C requires underwater excavation of large volumes of rock, excavation to depths greater than 150 feet below the operating water surface by construction procedures which are without precedent. In addition, a large part of the divide cut excavation spoil would have to be hauled to disposal in Gatun Lake which would drastically change the configuration of the residual lake. In contrast, practically all of the divide cut excavation for Route 14S could be made in the dry by methods for which there is ample precedent and a large part of the excavation spoil could be disposed of in the Pacific.

Excavation spoil deposited in Gatun Lake, whether it be in the form of barrier dams or non-functional waste areas, will rest on the soft Atlantic muck deposits forming the lake bottom. Stability studies for barrier dams in the central portion of the lake have shown that these weak materials create major dangers of massive slides during the rapid drawdown of the lake to sea-level, which is certainly required on the canal side of any spoil piles. Thus, regardless of the intended purpose of the spoil piles, very flat side slopes and all of the protective measures incorporated in the design of barrier dams will be required wherever the spoil is not confined by existing rock islands. This condition applies equally to Routes 14C and 14S although, for the latter, the volumes of spoil in the lake could be greatly reduced.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the considerations summarized in the preceding sections, the Technical Associates for Geology, Slope Stability and Foundations have reached the following conclusions and recommendations:

1. The physical feasibility of excavation of a sea-level canal by nuclear explosions is not now established. Therefore, nuclear excavation cannot be recommended for consideration for any canal that should enter construction within the next ten years. However, if design and construction of a new interoceanic canal are to be deferred one or more decades, nuclear excavation techniques hold promise of such great economic advantages that investigational and testing programs, as recommended in this report, should be pursued vigorously, but with the following exception. Attempts to excavate stable slopes in deep cuts in clay shale rocks by explosive procedures are so unlikely to produce acceptable or safe results that further investigations or tests in this direction are not recommended.
2. Assuming that nuclear excavation is now a feasible assured construction technique and in terms of the technical uncertainties and risks then remaining, the choice between Routes 17 and 25 is decisively in favor of Route 25 in spite of its greater length.
3. For routes constructed by conventional excavation the advantage of Route 10 being separated from the existing canal far outweighs potential difficulties and uncertainties in comparison with Routes 14C and 14S. If this route is selected, the Technical Associates recommend that the existing canal be maintained in an operational condition for at least ten years after a new separate canal has been placed in operation. By having the existing canal available in the event of a

temporary blockage of the new canal, Route 10 would justify economies which are inherent in an observational approach to the selection of design slopes, but which involve some risk of slides after completion of construction.

4. If for reasons not considered herein a route within the Canal Zone is considered imperative, construction of Route 14S introduces substantially fewer hazards and uncertainties than Route 14C. Route 14C would result in filling large portions of the Gatun Lake area with excavation spoil, which is not necessary for Route 14S, and has substantially increased hazards of canal blocking slides caused by the drawdown of water levels accompanying conversion to a sea-level canal. Major geologic surprises are not anticipated on these routes.
5. A valid comparison cannot be made between Routes 10, 14C and 14S, all of which would be excavated entirely by conventional means, and Routes 17 and 25, both of which require nuclear excavation for the planned construction. Nuclear excavation is not yet a proven construction technique and there is no assurance that construction plans and cost estimates based on present knowledge are valid. Therefore, dollar cost comparisons at this time have no true significance. The comparisons presented herein between Routes 17 and 25 are based on the assumption that assured feasibility of nuclear excavation can be developed by tests over the next decade or two, at which time construction on Route 25 might be planned with some confidence. If earlier construction of a sea-level canal should be recommended by the Commission, it is urged that the route selection be restricted to Routes 10 and 14S which can be constructed by presently known techniques of design and excavation.

The Technical Associates for Geology, Slope Stability and Foundations hope that this report, based solely on technical considerations of risks, uncertainties and favorable aspects of the several routes considered for a sea-level canal, will be of assistance to the Commission in its final deliberations and recommendations.

Respectfully submitted:

Arthur Casagrande

Arthur Casagrande, Consulting Engineer

Frank A. Nickell

Frank A. Nickell, Consulting Geologist

Roger Rhoades

Roger Rhoades, Consulting Geologist

Philip C. Rutledge

Philip C. Rutledge, Consulting Engineer

PCR:hc

Thomas F. Thompson

Thomas F. Thompson, Consulting Geologist

ENCLOSURE 3

LETTER FROM THE

ATOMIC ENERGY COMMISSION

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

July 7, 1970

Mr. Robert B. Anderson, Chairman
Atlantic-Pacific Interoceanic Canal Study Commission
Room 6217
726 Jackson Place, N.W.
Washington, D.C. 20506

Dear Chairman Anderson:

We were most pleased to have a report on the last meeting of the Atlantic-Pacific Interoceanic Canal Study Commission (CSC). With the tenure of CSC drawing to a close, we believe this is an appropriate time for the Atomic Energy Commission to provide the CSC with a brief status report concerning the work our laboratories have been doing in relation to nuclear excavation and our current estimate concerning what can be accomplished with further investigations.

Since the establishment of the CSC we have oriented our nuclear excavation experimental program so as to support the CSC studies and investigations. To date, we have not been able to do all the experiments which would be required to make a determination of the feasibility or infeasibility of using nuclear explosions for the excavation of the canals under study by the CSC. It is thus clear that any decision made to construct a sea-level canal in the near future must be made without being able to rely on nuclear excavation.

While we have not developed the technology sufficiently to make a specific determination of the feasibility of using nuclear explosions in the construction of a sea-level canal, our laboratories have made great progress in understanding the cratering processes and in designing explosives that minimize radioactivity. Some of their major technical achievements have been:

1. Development of a basic understanding of crater mechanisms. This understanding comes from theoretical studies, laboratory experimental work, and most importantly seven nuclear cratering experiments with yields ranging up to 100 KT. This understanding provides a greater degree of confidence in the calculations now used to design excavations, and also permits the specification of the important physical properties of rocks which must be determined so as to make these calculations.
2. The first nuclear row charge experiment had dimensions and other characteristics essentially as predicted.
3. Development of an understanding of seismic response through tests at the Nevada Test Site, which now has exceeded one megaton yields with no adverse effects.
4. Reduction of the radioactivity associated with excavation projects. An explosive specifically designed for excavation has been developed through a series of nine tests. The last one was the FLASK experiment executed in May 1970 in which a

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reduction of radioactivity, of a factor of five below our previous levels, was achieved. Although it is too late to incorporate the encouraging results from FLASK into the CSC studies, I believe that you will be pleased to know that if nuclear explosions were to be considered at some future date for canal construction the radioactivity would be an even smaller problem than is indicated in the reports presently being prepared for you.

5. Development of a predictive capability, through extensive measurements on nuclear cratering experiments, for the distribution of radioactivity in the fallback, ejecta, fallout, and long-range diffusion.

However, some technical problems still remain and require further work. While the understanding of cratering has been experimentally determined up to 100 KT, it is necessary to conduct experiments at yields up to a megaton. In addition, experiments are needed in rock of the same type as that expected along the routes of the canal, namely hard, water-saturated rock, and weak clay shales. Furthermore, additional experimentation is needed on nuclear row excavation to investigate close spacing concepts at high yields and to determine if there are any unknown practical problems associated with connection of rows. Additional work would also be useful in further reducing the radioactivity of excavation explosives.

The Lawrence Radiation Laboratory is working on a more detailed technical summary of the status of the excavation technology and the remaining questions. We will provide you a copy of the summary as soon as it is available.

The rate of development of the technology is not dictated so much by technical problems as by international considerations and public attitudes. The great current expression of public concern over the environment makes any experimental program such as this one difficult to accomplish. However, as the record clearly indicates, we have always proceeded in an extremely cautious manner in regard to environmental effects and we will continue to do so. Our large research effort to date in this area has led us to the conclusion that the risks associated with this application of nuclear energy can be kept to minimum acceptable levels while, at the same time, we can derive great benefits from its utilization. It is our opinion that, with the further improvements which we are confident can still be made and with greater public understanding of this technology, realistic environmental concerns can only diminish.

One of the factors we are faced with is the constraint of the limited test ban treaty. However, we have conducted our last five excavation experiments within these constraints and would, of course, conduct future experiments similarly.

As shown by the discussions which took place during the negotiation of the Nonproliferation Treaty, there is an awareness on the part of developing countries of the potential benefits under Article V of the Treaty. We also cannot ignore the excellent and aggressive program in nuclear excavation which has been described by the USSR, and particularly their stated plans for using this type of excavation on projects of a magnitude similar to the sea-level canal between the Atlantic and Pacific Oceans.

Our commitments, the interest on the part of the developing countries, and the USSR program not only establish a need for us to proceed with the development of nuclear excavation technology but also, we believe, will aid us in overcoming the political and emotional problems we currently face.

In summary, it is our view that, given the authorizations and funds, the problems regarding technical feasibility can be solved within a relatively short time. Each step we have taken in developing nuclear excavation technology has resulted in lowering the potential risk involved. At the same time, our increased understanding of the cratering mechanics has increased our belief in the potential benefit of this undertaking for mankind. Apparently the USSR has reached a similar conclusion concerning the benefits and risks and is proceeding accordingly. We believe that, if for any reason a decision to construct an interoceanic sea-level canal is delayed beyond the next several years, a nuclear excavation technology might be available and provide a realistic option in canal construction considerations at that time.

Sincerely,

Glenn T. Seaborg

Chairman

THE ATLANTIC-PACIFIC INTEROCEANIC CANAL STUDY COMMISSION

Annex I
Study of Foreign Policy Considerations

ANNEX I

STUDY OF FOREIGN POLICY CONSIDERATIONS FOR THE CONSTRUCTION AND OPERATION OF AN ATLANTIC-PACIFIC SEA-LEVEL CANAL

BY THE

FOREIGN POLICY STUDY GROUP

ATLANTIC-PACIFIC INTEROCEANIC CANAL STUDY COMMISSION

WASHINGTON, D.C.

AUGUST 1970

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CHAPTER I

HIGHLIGHTS AND CONCLUSIONS

SUMMATION

The Foreign Policy Study Group has identified four foreign policy advantages that would accrue to the United States if a sea-level canal were constructed in Panama. The Group has not encountered any insurmountable foreign policy disadvantages to such construction.*

A sea-level canal would:

1. Benefit the trading nations of the world, as well as serve United States international trade interests by resolving the canal capacity problem into the 21st century

2. Contribute to an enduring and sound relationship with Panama, which in turn would help ensure the continued availability of a dependable and efficient interoceanic canal to all maritime nations.

3. Facilitate strategic support for United States foreign policy, when required, through its decreased vulnerability and increased size which gives greater mobility to our ships.

4. Emphasize the role of the United States as an international leader, particularly if nuclear excavation could be used to demonstrate the power and promise of peaceful use of atomic energy.

In light of its mandate to concentrate upon the foreign policy aspects of a sea-level canal, the Study Group has not sought to determine whether the importance of the above advantages is sufficient to warrant the expenditure of scarce United States resources which have alternative domestic and international uses.

INTRODUCTION

The mandate of the Foreign Policy Study Group has been to determine and evaluate **foreign policy considerations** involved in the question of whether to build and operate a sea-level canal. We have not attempted to evaluate the desirability of such a waterway on other than foreign policy grounds. We have addressed the question of the addition of a third set of locks to the existing waterway, in so far as it provides an alternative to a sea-level canal in meeting essential United States interests.

The fundamental United States interest in a sea-level canal is the same as its interest in a lock canal: to provide an efficient and dependable means of interoceanic transit to the ships of all nations on a non-discriminatory basis at reasonable tolls in order to promote world commerce with attendant strategic and commercial advantages.

A dependable and efficient interoceanic canal can best be assured through an enduring good relationship with the host country.

*The question of the effect of a sea-level canal on ecology would, we assume, be resolved before beginning construction. If not, adverse international reaction to the ecological effect of construction would be a foreign policy disadvantage.

The Group recognizes that construction of a sea-level canal in Panama would commit the United States to responsibilities involving an indefinite extension of United States presence in Panama, and that there are problems associated with such presence. Given the commercial and strategic importance to the United States of a transisthmian waterway, however, the Group accepts the fact that some United States presence in Panama would necessarily be extended whether or not a new canal is constructed, and considers the problem manageable under satisfactory new treaty arrangements.

The main foreign policy considerations for the construction and operation of a sea-level canal relate to:

- The importance of a transisthmian passage to United States international relations.
- United States bilateral relations with the host country.
- How we might build a sea-level canal, where we might build it, how we might operate it.

IMPORTANCE OF THE CANAL TO UNITED STATES INTERNATIONAL RELATIONS

INTERNATIONAL TRADE

United States Trade Through the Canal.

The *Report of the Study Group on Interoceanic and Intercoastal Shipping* demonstrates that the capacity of the existing canal in terms of numbers of transits would probably be reached by the end of this century, if not sooner. Seventy percent of the tonnage of cargo transiting the canal originates or terminates in United States ports. For FY 1969 this portion of canal traffic amounted to some 70 million tons and constituted 10% of the value of our foreign trade. Yet, as of 1970 there were about 1300 ships afloat, under construction, or on order which were too large to enter the Panama Canal locks. In addition, there were approximately 1750 more ships in these categories that could not pass through the canal fully laden at all times because of draft limitations due to seasonal low water level.

Limitations on quantity and size of ships transiting the canal can complicate commerce by making shipping more costly and difficult, by causing economic dislocations for suppliers, and by restricting supplies to consumers. These limitations thus could tend to retard the expansion of our international trade.

Proceeding with the construction of additional canal capacity in the face of possible deficits from the operation, however, may be regarded as an uneconomic use of our resources.

Other Nations' Trade Through the Canal.

The two groups of other principal users include our major trading partners, and other friendly nations assisted by the United States and international agencies in developing their economies. The potential adverse effects listed above on United States commerce also apply to these other nations which utilize the canal.

Many commodities, particularly petroleum, ores, metals and coal, which are the highest tonnage items transiting the canal, are so competitive that significant changes in shipping

costs can cause shifts to alternative sources of sup^pl^ Such bulk cargoes, however, can most easily avoid the canal by using larger ships and alternative ship routing.

These bulk items are frequently important sources of foreign exchange for developing nations. Poorer nations would also suffer should transportation difficulties limit supplies or raise costs of food, grains and other agricultural commodities that are significant items in canal traffic. Should the canal fail to serve world trade adequately, we would be blamed because we are identified in world opinion as being responsible for the efficient operation and defense of the transisthmian waterway.

Providing such service, however, especially through an outstanding engineering achievement, would be harmonious with our position of world leadership, would be consonant with our publicly stated intention to continue to accommodate world commerce, and would demonstrate our continuing interest in hemispheric development and expanding trade among the nations of the world.

Alternatives for Expanding Canal Capacity

(a) The existing canal can accommodate ships of 65,000 DWT. It has a maximum potential capacity of 26,800 transits per year with improvements costing up to $100 million. Such investment would not, however, meet the problem of accommodating larger vessels.

(b) A third set of locks would expand the capacity to about 35,000 transits per year. Construction of locks to accommodate ships up to 150,000 DWT would cost about $1.5 billion. Such expansion would probably accommodate vessels in the trade into the 21st century.

The proponents of the third lane of locks concept believe it has a major political advantage, namely, that it can be built under the provisions of existing treaties. The Panamanians oppose this view, although they agreed in a 1939 exchange of notes clarifying the 1936 Treaty that the United States could undertake additional construction- and we, in fact, did.

(c) The sea-level canal preferred from an engineering point of view, i.e., along Route 10, could accommodate up to about 66,000 transits per year, depending on the success in overcoming technical limitations such as tidal currents. Its minimum capacity is estimated at 38,000 transits per year. Construction cost would be about $2.9 billion. It would accommodate ships up to 150,000 DWT under all conditions, and would accommodate ships up to 250,000 DWT under favorable tidal conditions. Other alternatives are feasible but have higher construction costs. If restrictive technical conditions prevailed this would resolve the capacity problem only until the early part of the next century. Under optimum conditions capacity problems would be resolved beyond the middle of the 21st century. Under both conditions the canal could be expanded, at additional cost, for as much capacity as required in the future. New treaty arrangements with Panama would be required.

Operation of the sea-level canal described above in conjunction with the existing canal would provide even greater capacity and flexibility.

We conclude that United States trade interests would best be served by our arranging to provide additional canal capacity before demands for transits exceed capacity. A sea-level canal or canal system would best serve our long term trade interests.

STRATEGIC CONSIDERATIONS

Our ability to defend the canal and thereby assure its continuing operation is of importance in enabling us to defend ourselves and assist our friends militarily. Whether the canal is lock or sea-level is of great importance in this regard.

Vulnerability of a Lock Canal

A lock canal is highly vulnerable both to sabotage and to various forms of military attack. It is difficult to safeguard. The Defense Study Group has concluded that a sea-level canal would be far less vulnerable than either the present canal or any of the modernized versions of a third lock canal.

Mobility of Forces and Materiel

A secure isthmian canal is important to the effective support of military operations overseas. From the standpoint of foreign policy this means increased availability of military resources to support our foreign policy objectives to the extent that such support is required. It implies the need for a canal that will accommodate the increased size of both naval and merchant ships.

We conclude that the canal is important for our national defense as well as for the military support of our foreign policy. According to the Defense Study, considerations of vulnerability and size which inhibit our strategic capabilities are best overcome by a sea-level canal.

UNITED STATES BILATERAL RELATIONS WITH THE HOST COUNTRY

BACKGROUND OF OUR RELATIONS WITH PANAMA

Sources of Friction

The 1903 Treaty, amended in 1936 and 1955, has been a continuing source of friction in United States–Panamanian relations. The principal points at issue have included the following:

(a) Panama's desire to derive a greater share of the economic benefits resulting from canal operations.

(b) The grant to the United States of "the rights, power and authority within the zone...which the United States would possess and exercise if it were the sovereign of the territory...to the entire exclusion of the exercise by the Republic of Panama of any such sovereign rights, power or authority." This conflicts with Panamanian aspirations concerning the most important asset on the isthmus–the canal.

(c) The presence and the life-style of a large United States community living adjacent to Panama's urban areas (there are approximately 38,000 United States military and civilian personnel living in the Canal Zone).

Recent Developments

The 1936 and 1955 amendments to the treaty, as well as the 1962-63 discussions between Presidents Kennedy and Chiari, reflected efforts to deal with frictions caused by existing canal arrangements without fundamental change in treaty structure. Failure to satisfy basic Panamanian aspirations caused growing frustration that erupted in the January 9, 1964 riots, in which in least 18 Panamanians and 4 American soldiers were killed, over 100 persons were injured, and property valued at several million dollars was destroyed.

On December 18, 1964, President Johnson issued a statement declaring that the present canal would soon be inadequate for the needs of world commerce and that he had decided to (1) press forward with plans for a sea-level canal; and (2) propose to the Government of Panama the negotiation of an entirely new treaty for the existing canal.

On June 26, 1967, President Johnson announced that the negotiating teams had reached agreement on the form and content of three interrelated treaties covering the existing canal, a new sea-level canal, and canal defense. These treaties were never submitted for ratification by either government.

If a sea-level canal were to be constructed, its value in terms of United States-Panamanian relations would be judged on the degree to which it made possible a more enduring good relationship by facilitating the resolution of the principal points at issue between the two countries.

CANAL ADMINISTRATION AND ECONOMIC BENEFITS

Value of the Asset

A sea-level canal would be simpler to operate than a lock canal and would be less subject to interruption. Thus, administrative arrangements would be simplified.

Its construction would also create economic benefits for Panama and assure that all foreseen requirements for ship transits are met in Panama rather than in another country.

Benefits to Panama

Construction of a new canal anywhere in Panama or improvements to the existing canal could be beneficial to that nation's economy. These benefits could result both from the increased economic activity during the construction period and from the additional revenues from increased traffic which would be available to Panama if a revenue-sharing arrangement were adopted.

The Stanford Research Institute estimates that in peak construction years, based on the method and route of construction, Panama's Gross Domestic Product would be from 6.3% to 9.5% higher than it would be without construction.

JURISDICTION

There are characteristics of a sea-level canal which would lend themselves more readily than those of a lock canal to the satisfaction of basic Panamanian aspirations of exercising jurisdiction in the Canal Zone. Without the requirement for sensitive locks and generating

plants, and large numbers of foreign personnel, it would be possible to reduce the Canal Areas to a minimum and to permit a broader exercise of Panamanian jurisdiction in these areas. This presumes that a sea-level canal would be operated instead of, not in addition to, the lock canal. This particular advantage would not be attained if the sea-level canal and lock canal were operated as a system.

THE LARGE FOREIGN PRESENCE

United States presence in Panama is emphasized both because of the number of American residents and because the United States is such a large employer. A sea-level canal would require about 2200 operating employees compared with the 5000 required to operate and maintain the present canal. The present canal complex also has approximately 10,000 additional employees engaged in providing the entire spectrum of commercial activities and community services for the Canal Zone. This latter group, too, could be drastically reduced under new arrangements. Most of the services performed by these 10,000 employees could be provided by the Panamanian business community and government, and need not continue as functions of the canal operating authority. Since a sea-level canal if operated by itself would not have vulnerable lock installations, the military force protecting it could be less pronounced. The size and visibility of a separate affluent community of foreigners within Panama would be reduced.

We **conclude** that construction of a sea-level canal would facilitate a more enduring good relationship with Panama than would augmenting the existing canal. It would also secure more certainly the availability of an efficient and dependable canal. Construction of a sea-level canal would bring important economic advantages to Panama, thereby further contributing to the enduring and sound relationship we seek.

FOREIGN POLICY CONSIDERATIONS IF A CANAL WERE CONSTRUCTED OUTSIDE OF PANAMA

Construction outside of Panama would cause grave repercussions in our relations with Panama. The canal-centered economy of Panama would be disastrously affected.

Colombia

Because of the more diversified Colombian economy, a canal in Colombia would not play the major economic role it does in Panama. On the other hand, making arrangements for the defense of the routes in Colombia would pose difficult political questions for the United States and Colombia, and the cost of building and maintaining defense facilities would be higher for the Colombian than for the Panamanian routes. The major foreign policy difficulty would be the serious consequences to United States relations with Panama.

We **conclude** that construction of a sea-level canal on Route 25 would merit further consideration only in the event that mutually acceptable arrangements could not be reached between the United States and Panama for construction of additional canal capacity in that country.

Nicaragua

The Nicaragua-Costa Rica Route has been discarded from further consideration by the Canal Study Commission because of its expense in comparison with other canal routes. Route 8 offers no significant foreign policy advantages that would counter-balance other arguments against construction in that area. In light of these considerations, the United States has moved to terminate its 1914 treaty relationship with Nicaragua (the Bryan-Chamorro Treaty) that grants the United States the right in perpetuity to build a canal across Nicaragua.

We **conclude** that construction of a sea-level canal along Route 8 is not a feasible project.

HOW WE MIGHT BUILD A SEA-LEVEL CANAL, WHERE WE MIGHT BUILD IT, HOW WE MIGHT OPERATE IT

NUCLEAR EXCAVATION

The prestige the United States would derive from having constructed a sea-level canal would be enhanced if it were to prove feasible to employ nuclear excavation. The USSR is moving ahead with a series of projects which give that nation an opportunity to demonstrate its own advances in the field of peaceful uses of atomic energy. The excavation of a sea-level canal by nuclear means would provide the United States a unique opportunity to demonstrate progress on its part in this field on a massive scale.

Nuclear excavation would, however, raise fears regarding physical harm to individuals and the disruption of their lives. Residents of the area chosen would have to be relocated during construction. Evacuation would affect over 3,000 square miles and involve perhaps 10,000 people on the best route for nuclear excavation. The psychological and sociological implications present problems that could prove formidable.

The restrictions of the Limited Test Ban Treaty on the use of nuclear explosives pose another problem. It is not possible to determine whether or when international agreement can be reached that would permit the use of nuclear explosives in Isthmian canal construction.

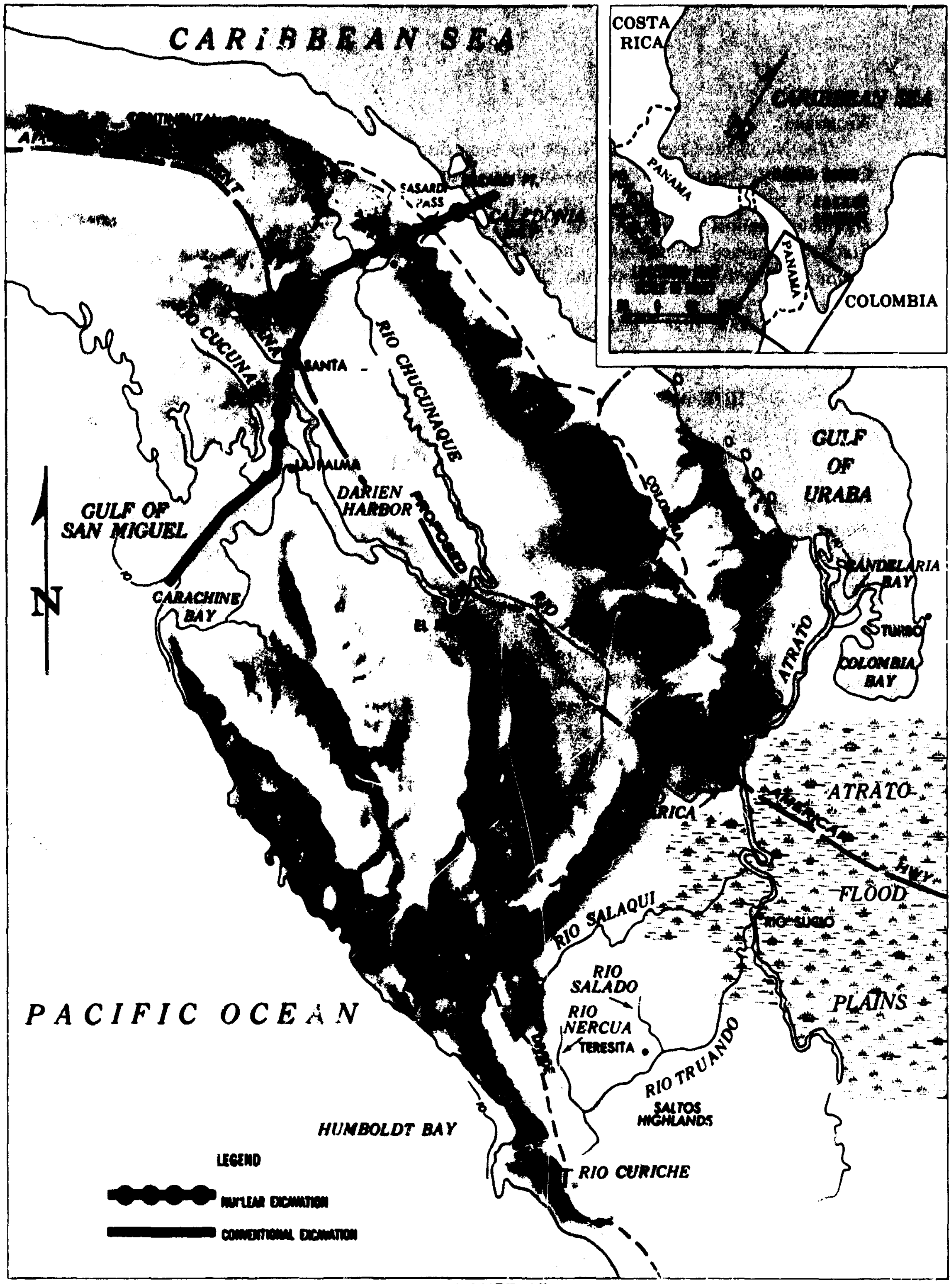
The technical feasibility of nuclear canal excavation has not been established. Determination of technical feasibility and removal of international treaty obstacles to nuclear excavation would still leave great political and economic objections to a sea-level canal remote from Panama's metropolitan centers.

We **conclude** that, based on information currently available, nuclear canal excavation is not now possible.

DESIRABILITY OF VARIOUS ROUTES IN PANAMA

Route 17 (Figure I-1)

A sea-level canal in the Darien region would be more than 100 miles from the population centers of Panama and therefore should remove some of the lesser causes of friction. Sparsely populated areas of Panama would be developed if this route were chosen. Both of these advantages would probably be counter-balanced, however, by the foreign policy problems attending nuclear excavation and by the economic dislocation involved.



ROUTE 17

FIGURE I-1

PANAMA-COLOMBIA BORDER AREA

SCALE IN MILES

5 0 5 10 15 20 25 30 35

DEPTHS IN FATHOMS

The flow of resources into the development of the remote Darien region which would result from the construction of the canal there would take place to the economic detriment of the Panama City-Colon metropolitan areas. About $300 million per year in economic activity would shift with the canal. Although in the long run construction of a canal in Panama remote from the present one would probably not cause significant overall economic changes in the structure of the economy, major short run economic dislocations would result.

Route 10 and Route 14 (Figure I-2)

Both routes in the area of the present canal have the same general foreign policy implications. The advantages of a sea-level canal are not adversely affected by any major foreign policy considerations here. New treaties with Panama would be required to permit construction. There might be some inflation during the construction period and some deflation with the opening of a sea-level canal requiring less manpower than the lock canal, but in neither case would it be substantial enough to stir up new antagonisms if the treaty terms for the new canal were acceptable to both parties. Route 14 has the advantage of being within the present Canal Zone while Route 10 would require special arrangements with Panama to acquire land and access rights. The risk of long term closure of the existing canal during the construction period and its permanent elimination as a canal with the opening of a sea-level canal on Route 14 are major drawbacks to this route.

The proximity of both routes to the principal metropolitan areas raises the problem of friction between the canal administration and the local population. The reduction of personnel envisaged through a sea-level canal would ease this problem. At the same time, availability of labor and supplies from the nearby Panamanian cities for the construction and operation of the canal provides positive benefits both to the Panamanian economy and to the United States.

Continued Use of the Lock Canal Along with a Sea-Level Canal

The greatest flexibility in the United States choice of alternatives and timing of new construction, as well as the largest total capacity at least cost, are offered by operating the old canal and a sea-level canal on Route 10 as a single system within the context of new treaty arrangements.

We conclude that the order of preference of the sea-level canal routes in Panama on foreign policy grounds is: Route 10, Route 14, Route 17.

POSSIBILITY OF INTERNATIONAL ADMINISTRATION

There has long been discussion concerning the possibility of arranging some form of multinational participation in the operation of an Isthmian canal. The 1967 treaty drafts contain provisions for multinational participation in the financing, ownership and operation of a sea-level canal, but the exact terms of any arrangement are left open for future agreement. While United States interests might be served by some form of multinational participation in the future, the foreign policy benefits do not appear great.

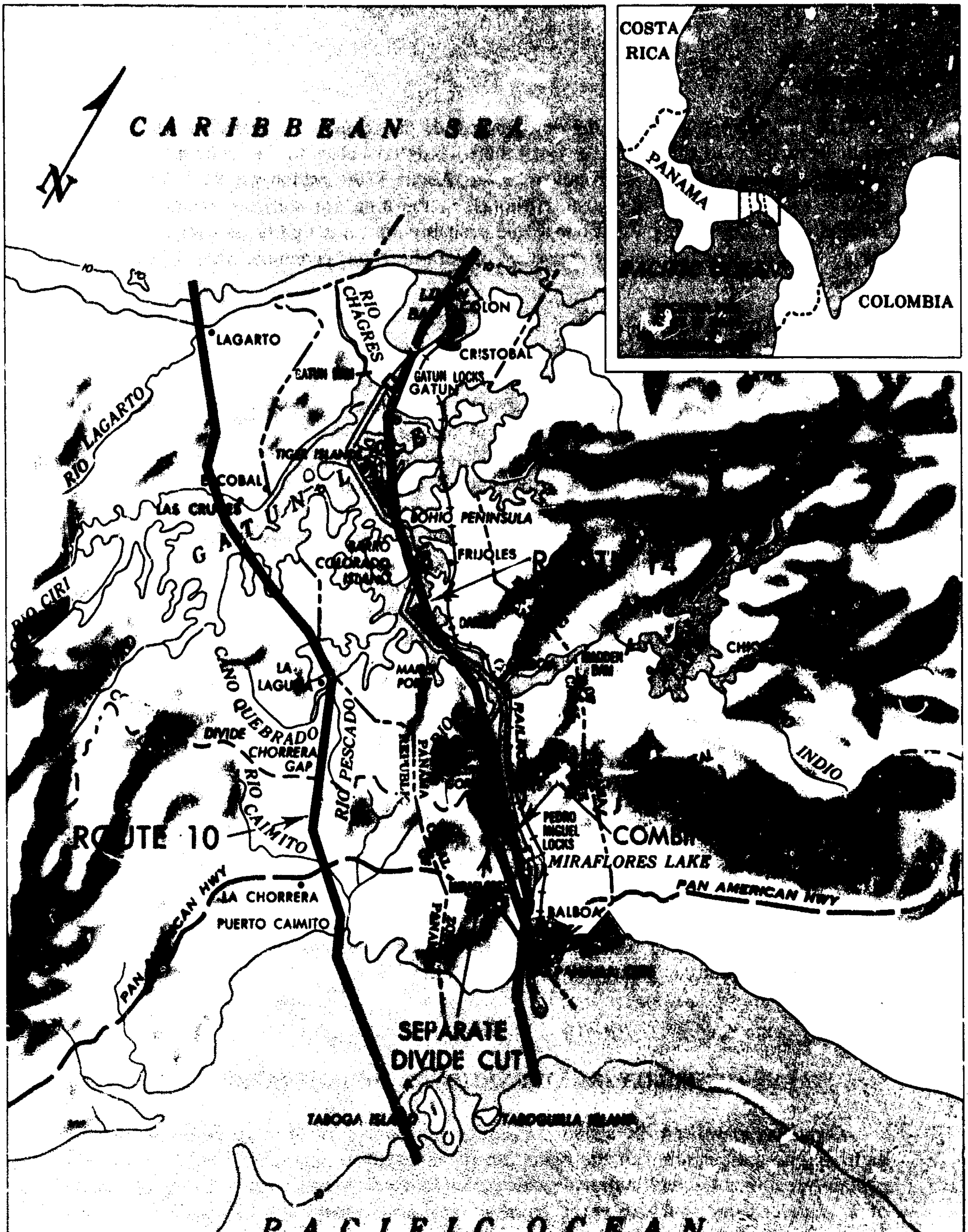


FIGURE I-2

THE [illegible] ZONE AND VICINITY

SCALE IN MILES
5 0 5 10

DEPTH IN FATHOMS

Panama has been cool toward multilateral arrangements for the canal. The inducements for multinational participation are not great to major user nations, who appear to believe that the operation of an Isthmian canal is primarily a United States responsibility.

We **conclude** that international participation in a sea-level canal is unlikely of attainment under foreseeable circumstances. Over the long run, however, some form of international participation may be obtainable and may be the best long-term guarantee of United States interests.

CHAPTER II

HISTORICAL BACKGROUND

The United States and Panama have been engaged in a partnership which has produced great benefits for both countries, but which from the beginning has also been the source of antagonism between them. The antagonism is compounded by the vast differences in size and wealth, by the divergent interests of the two countries in the management of the canal, and by barriers of language and culture.

In 1964 this interdependent but uneasy relationship suffered a setback. In that year the subtle and complex issues which had stood between the two countries for sixty years were reduced to symbols, conveniently simplified in a confrontation of flags. The youths of the two nations used the symbolic representations of their nations to influence the course of events. They tried to upset the agreement reached by their governments in 1963 that Panamanian titular sovereignty over the Canal Zone would be recognized by flying the Panamanian flag wherever the United States flag was displayed. The determination of each student group to raise its nation's emblem on the flagpole of an American school in the Zone led to three days of rioting and the death of at least 22 persons. Panamanian demands for a basic restructuring of the canal partnership took on added urgency.

United States Interest in an Isthmian Crossing

Even before the United States began to face two oceans, American statesmen were convinced of the need to guarantee unobstructed passage across the Isthmus. This interest grew when the country's western frontier finally reached the Pacific with the settlement of the Oregon boundary in 1846, and especially after gold was discovered at Sutter's Mill and '49ers found the Isthmus to be the principal route to California. The United States then sought to check the spread of British influence in the area, and to guarantee for itself unimpeded passage over the existing routes and through any canal crossing that might be built. In 1846 the United States Ambassador to New Granada (Colombia), which then controlled what is now Panama, negotiated a treaty in which the United States recognized New Granadan sovereignty over Panama, and New Granada guaranteed to United States citizens the right to passage across the Isthmus on the same basis as to the citizens of New Granada.

In the face of expanding British presence in Central America, the United States concluded the Clayton-Bulwer Treaty with Britain in 1850 to assure that any canal constructed on the Isthmus would be neutral and that neither country would fortify or exercise domain over any part of Central America. Later, in response to the clear United States intention to build a canal somewhere on the Isthmus, Britain agreed, in the Hay-Pauncefote Treaty of 1901, that the United States could operate and defend a new canal provided its neutrality as a shipping lane were maintained.

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The Beginning of a Partnership

United States-Panamanian relations had their beginning, and take much of their character, from a period in which the United States was emerging as a world power. The Spanish-American War established the United States as the prime power in the Caribbean and aroused new interest in that area among people in the United States. The sixty-six-day journey of the battleship "Oregon" around Cape Horn during the war dramatized how advantageous a canal would be for United States strategic policy.

The treaty that established the association between the United States and Panama was more favorable to the United States than the Hay-Herran Treaty which the United States had been ready to accept a year before, but which the Colombians had refused to ratify. The Panamanian leaders arrived in Washington just after the Convention for the Construction of a Ship Canal was signed, and though they were dissatisfied with some of its provisions, they apparently were relieved to have a treaty and signed it. The treaty was ratified by both sides, but Panamanian objections were registered with growing intensity over the years that followed.

Panama Seeks to Undo the 1903 Treaty

Panamanian nationalists today see the treaty as an intolerable derogation of their country's sovereignty. Both the wording of the treaty, and the way the United States put its provisions into practice, have much to do with Panamanian resentment. In the early years of Panama's independence, during the construction and initial operation of the canal, conditions on the Isthmus caused the United States to adopt practices it probably would have avoided if sanitation had been less of a problem, if Panama's economy could have better supplied the needs of the Canal Zone, and if Panama's population had had the skills to perform the tasks of canal construction and operation.

The United States Government operated the largest commercial enterprise in Panama, supplying goods at reasonable prices to the workers, adequate sanitary housing, and stores to ships passing through. Our Government even went into the hotel business. The commissaries which were established within the Canal Zone became a continual source of irritation to Panamanians who saw themselves excluded from the opportunity to exploit canal-related commerce.

This problem was first dealt with in the Hull-Alfaro Treaty of 1936 which restricted sales in the commissaries to direct-hire employees of the United States Government, members of the United States Armed Forces, and certain others, provided the latter actually lived in the Zone. In the same treaty the United States agreed to close the Zone to the establishment of new private business, except to those engaged in canal related activities.

In the 1955 Treaty of Mutual Understanding and Cooperation between the United States and Panama, it was agreed that only those Panamanian employees who actually lived within the Zone would be allowed to use the commissaries. The 1955 agreement also carried a memorandum of understanding in which the United States agreed to limit sales to passing ships to petroleum, oil, and lubricants, and to give Panama, along with the United States, a larger right to the Canal Zone market.

The Panamanians, of course, were not just interested in the indirect benefits that canal related commerce could bring. They also demanded more direct benefits through the canal annuity. Under the 1903 Treaty Panama received an immediate $10,000,000 payment, and a United States promise to pay $250,000 in gold dollars each year. In the 1936 Treaty, as an adjustment for the 1934 reduction in weight of the United States gold dollar, the annuity was changed to $430,000. The annuity was increased to $1,930,000 in the 1955 Treaty. However, Panamanians insisted that the amount was too low, and urged the United States to raise tolls to allow higher annuity payments.

The changes made by the 1955 Treaty contributed to the economic up-swing that began in Panama in the late fifties. To the Panamanians, however, progress in implementing the provisions of the treaty seemed slow, and this was one of the major points of discussion in the meetings between the two countries' Presidents in 1962.

The cultural, political, and philosophical differences between those who came to construct and operate the canal and those who were descended from the Spanish colonizers may be more important than the economic considerations. The distinction between the skilled workers, mostly from the United States, and the local laborers, from Panama and the Caribbean, was also soon clearly drawn by the practice of paying the former in gold and the latter in silver.

Even after the specie payment was abandoned, "gold" and "silver" signs directed each class to separate public utilities, including drinking fountains, post office windows and rest rooms. These signs were finally painted over in 1946. A carry-over from the old specie payments was also seen in a double set of wage standards. Although Panamanians were eligible for "United States rate" positions, most in fact worked in "local rate" jobs.

This dual payment system was considered by Panamanians to be a form of discrimination against them in their own country. Provisions in the memorandum of understanding annexed to the 1955 Treaty sought to establish equal employment conditions for Panamanian and United States citizen employees of the United States Government in the Zone. Separate rates of pay were abolished, and the right of Panamanians to compete for jobs at all levels was recognized. The United States committed itself to creating training programs to help qualify Panamanian employees for more responsible positions. For the last several years increasing emphasis has been placed on providing employment opportunities in higher paid positions to non-United States citizens. Since it would be uneconomical to recruit unskilled employees from the United States, the lowest paid positions continue to be filled by Panamanians.

Pressure Begins to Build

In the late 1950's, United States policy came under increasing attack. In this rising climate of anti-Americanism, Panamanians, particularly the student population, stepped up their protests against the United States presence. In 1959 demonstrations were organized for the first time against the Canal Zone. On Panama's Independence Day, November 3, 1959, a "sovereignty march" entered the Zone to plant the Panamanian flag. The demonstrators were pushed back by Zone police and violence followed in the streets of Panama City.

The United States, which had granted substantial concessions in 1955, moved quickly to cap the rising pressures building within Panama. President Eisenhower dispatched Livingston Merchant as Special Ambassador to Panama. At a public ceremony, Ambassador Merchant publicly voiced recognition of Panama's "titular" sovereignty over the Canal Zone. Efforts were made to reconcile Panamanian opinion and in September, 1960 the United States agreed that Panama could raise its flag at one prominent place in the Zone to symbolize Panama's titular sovereignty. The flags of both countries were raised at Shaler Triangle on November 25, 1960, but even this step was marred when the chiefs of the three branches of the Panamanian Government declined to attend the inaugural flag raising because a Panamanian was not allowed to hoist the flag.

The Kennedy Years

United States-Panamanian relations continued to be strained throughout the years of the Kennedy Administration. In June of 1962 Presidents Kennedy and Chiari met, and agreed to bilateral discussions to find those points of friction that could be resolved within the framework of the existing treaty arrangements. The United States Ambassador to Panama, Joseph Farland, and the Governor of the Canal Zone, Major General Robert Fleming, were appointed to represent the United States at the discussions in Panama.

One of the few changes which was agreed upon was the use of the Panamanian flag wherever the United States flag was flown. The new rule was adopted in steps throughout the Zone, and in January, 1964 it was applied to the United States high schools in the Zone. But in practice, it was decided that United States flags would no longer be displayed outside the schools, in order to avoid the construction of a number of duplicate flag poles.

The 1964 Crisis

The youth of the two nations set the course of events. On January 7 the American students of Balboa High School in the Zone ran the Stars and Stripes up the flag pole in front of their school. The flag was taken down by school authorities, but the students ran it up again. On January 9 a large group of Panamanian students entered the Zone determined to raise the Panamanian flag in an equal position. A scuffle with the Zone police followed and the Panamanian flag was torn.

A large Panamanian crowd claiming desecration of their flag formed along the Zone border and for the next several days rioting in Panama City and Colon was marked by attempted intrusions into the Zone by rioters, and sniping into the Zone by persons in tenements across the border. The rioters, mostly students and laborers, were urged on by radio and television, and by agitators. By January 12 when the rioting finally ended, there were at least 18 Panamanians and four United States soldiers dead and more than 100 injured on both sides.

The government of President Chiari accused the United States of aggression, and broke diplomatic relations. It demanded that an emergency meeting of the Council of the Organization of American States be called as provided for under the Rio Pact, and also that a meeting of the United Nations Security Council be convoked according to the United Nations Charter. Later, Panama claimed that the United States had violated the Delcaration of the Rights of Man, and appealed to the International Commission of Jurists.

The conclusions of the investigating committee appointed by the International Commission of Jurists did not support the allegation that the United States had violated various articles of the universal Declaration of the Rights of Man. Moreover, it regretted that the Panamanian authorities made no attempt during the critical early hours, as well as for almost three days thereafter, to curb and control the violent activities of the milling crowd. But at the same time, it urged the United States to take effective steps to make possible a reorientation and change in the outlook and thinking of the people living in the Canal Zone.

President Johnson, confronted with this crisis after only a month in office, dispatched a special mission to Panama to encourage restraint and an end to the violence. He expressed a willingness to discuss all issues, but only in an atmosphere of calm and reason. Though diplomatic relations were resumed three months later, the ensuing period demonstrated the depth of each country's feelings and marked the gulf between them.

The Presidential announcement in December 1964 that the United States was prepared to negotiate an entirely new treaty with Panama and that we should press forward with plans for a sea-level canal signaled the beginning of a new stage in United States-Panamanian relations.

CHAPTER III

THE CASE FOR A SEA-LEVEL CANAL

The idea of a sea-level canal is not new. A sea-level canal across the American isthmus that could safely and efficiently transit all the world's ships has been a goal of canal planners since the narrow crossings were discovered by Balboa four and one-half centuries ago.

The "battle of the levels" began in earnest in 1875, when Suez Canal builder Ferdinand de Lesseps persuaded the International Congress for Consideration of an Interoceanic Canal to vote to build a sea-level canal in Panama after a lengthy debate over the merits of a high-level lock canal. Construction began in 1881, but the engineering and health problems were overwhelming at the time. Mismanagement, disease, and impending bankruptcy led to a reluctant switch to a more easily built lock canal as an attainable goal. Nevertheless, even this reduced effort failed. In 1903 the historic objective of a sea-level canal was revived in the United States. President Theodore Roosevelt's Board of Consulting Engineers voted 8 to 5 for a sea-level canal, the Senate Committee on Interoceanic Canals favored a sea-level canal by 6 to 5, but the Senate as a whole decided upon a lock canal by a vote of 36 to 31. While acknowledging the ultimate desirability of a sea-level canal, the Senate chose to construct the less costly lock canal initially.

Several recent major studies of the Panama Canal have continued to endorse the long-range goal of a sea-level canal:

– In 1947 the Governor of the Panama Canal reported pursuant to Public Law 289, 79th Congress, which required a canal study, that: "a sea-level canal constitutes the only means of meeting adequately the future needs of commerce and national defense, and such a canal can be obtained most efficiently and economically by converting the present Panama Canal to sea-level".

– In 1960 the President of the Panama Canal Company reviewed the 1947 study and recommended immediate investigation of the possibility of excavation of a sea-level canal by nuclear methods. If the nuclear-excavation technology were not developed by the early 1970's, he believed that plans should be made for the conversion of the existing canal to sea-level by conventional methods.

– In its Report on a Long-Range Program for Isthmian Canal Transits in 1960, a Board of Consultants to the House Committee on Merchant Marine and Fisheries concluded that "the ultimate solution to the basic problem of increasing the capacity is probably a sea-level canal, but its construction should await a traffic volume that can support the large cost".

President Johnson's Decision

In March of 1964, President Johnson asked Congress for authority to conduct a new sea-level canal study. A bill was approved in September as Public Law 88-609. On December 18, 1964, the President announced his decision to begin international discussions of the possible construction of a sea-level canal, and to negotiate new treaties with Panama

to replace the treaty of 1903. In his statement the President said: "So I think it is time to plan in earnest for a sea-level canal. Such a canal will be more modern, more economical, and will be far easier to defend. It will be free of complex, costly, vulnerable locks and seaways. It will serve the future as the Panama Canal we know has served the past and the present" The President's decisions stemmed from an awareness that new treaties could meet many of Panama's aspirations in the Canal Zone and still protect United States interests in the Canal.

A sea-level canal would require a direct operating staff of approximately 2200 persons, of whom few need be skilled United States technicians. This compares with the nearly 5000 operating personnel of the present canal supported by some 10,000 additional Canal Company and Canal Zone Government employees who provide the entire range of community services to the canal operators and a large part of such services for the Zone's military bases. Some 5000 of this 15,000 total are United States citizens.

An alternative way to meet world trade demands of the immediate future would be to add a third set of locks to the existing canal. Such a canal, however, would not accommodate trade needs for the more distant future because of the number of ships that are expected to seek passage. Moreover, it would increase the requirement for operating personnel.

A sea-level canal, on the other hand, would under optimum conditions accommodate world traffic for the foreseeable future and would permit a major reduction in personnel. The less vulnerable and more easily defended sea-level canal offers significant political advantages. It would permit greater United States flexibility in canal defense arrangements. Should the United States decide to build a sea-level canal and to operate it in conjunction with the lock canal, it would have to provide canal defense arrangements for both routes. These arrangements should be possible with no increase in defense personnel.

CHAPTER IV

PANAMA AND A SEA-LEVEL CANAL

UNITED STATES–PANAMANIAN BILATERAL RELATIONS

Relations between the United States and Panama are concerned primarily with the Panama Canal, which has been true ever since Panama attained its independence. The United States interest is to guarantee the continued existence of an efficiently operated and adequately defended interoceanic waterway that charges reasonable tolls and is open on a non-discriminatory basis to the traffic of all nations. The Panamanian view is that its geographic location, which makes a canal possible, is Panama's greatest natural resource, one it has the right to exploit in what it deems to be its own best interests. Striking a mutually satisfactory balance between the differing interests of the two nations in the canal is a primary concern of United States policy toward Panama.

After President Johnson's statement of December 18, 1964, United States policy was directed toward negotiating new treaties that would eliminate some of the causes of friction over the existing canal and secure for the United States the right to construct a sea-level canal in Panama. By June of 1967, United States and Panamanian negotiating teams had reached agreement on three treaty drafts and referred the drafts to their respective governments for consideration.

SUMMARY OF 1967 DRAFT TREATIES*

Lock Canal Treaty

The draft treaty covering the existing canal contains the following essential points:

1. Existing treaties would be abrogated.
2. The canal and all properties and adjuncts, and the administration of a reduced "Canal Area" would be transferred to a bi-national Administration governed by a Board of Governors composed of 5 Americans and 4 Panamanians appointed by the respective Presidents for six-year terms subject to removal for cause by the appointing Presidents.
3. Executive and legislative powers relative to the administration of the canal and Canal Areas would be vested in the Joint Administration, subject to detailed treaty provisions.
4. The Administration would have the right and power to set up a court of general jurisdiction to deal with civil and criminal cases in the Canal Areas. United States armed forces and their American civilian component would be subject to special (status of forces) provisions under the Defense Treaty.
5. Panama would be sovereign over the Canal Area, subject to jurisdiction vested in the Joint Administration in matters directly related to canal operations.

*It should be noted that the assumptions now adopted regarding the construction of a sea-level canal are different from those which existed when the draft treaties were negotiated.

6. The United States Government, as such, would have no direct control over canal operations or the Canal Area; it would have a one-man majority on the Board of Governors of the Joint Administration, by virtue of the five members appointed by the President on the nine-man Board.
7. The Treaty would terminate, and the canal and Canal Area become the property of Panama, on December 31, 1999, or sooner if a sea-level canal were opened before then, or no later than 2009 if a sea-level canal were under construction on December 31, 1999. (**Comment**: If no sea-level canal were to be constructed the existing canal would thus become Panamanian property on December 31, 1999.)
8. Panama would receive royalties paid from tolls, based on the amount of traffic through the canal.

Sea-Level Canal Treaty

The draft sea-level canal treaty would in effect give the United States an option to build a sea-level canal with certain essential terms to be arrived at through subsequent negotiation, including financial arrangements, the use of nuclear excavation in construction, and the identification of land areas. Additionally:

1. The option would extend for 20 years.
2. The United States would finance the canal but could, after consultation with Panama, arrange for international and private participation.
3. The canal would be operated by an Interoceanic Canal Commission, governed by 5 Americans and 4 Panamanians as in the draft treaty for the present canal, with provisions for additional members representing other financial participants, if any.
4. The treaty would terminate, if the United States exercised its option to build, 60 years after the sea-level canal was opened but no later than December 31, 2067, and the canal and all related properties would revert to Panama.

Defense Treaty

The third treaty would establish defense bases in Panama from areas now in the Canal Zone and would constitute, in effect, a status of forces agreement of the type negotiated with other countries. Additionally:

1. The United States would provide for the defense, security and continuity of operation of the existing canal, its related facilities, and the Canal Area, and of a sea-level canal if built.
2. Defense bases would be made available for canal defense and related security purposes.
3. The treaty would terminate 5 years after the lock canal treaty terminated, or whenever the United States was no longer committed by treaty with Panama to defend a canal in Panama, whichever time came later.

These treaty drafts have not been submitted for ratification by either country. However, the initial United States commitment to undertake treaty negotiations has brought about an improvement in United States-Panamanian relations since 1964.

ALTERNATIVE CANAL SITES IN PANAMA (Figure IV-1)

In his announcement of December, 1964 President Johnson listed four possible canal routes for investigation: two routes in Panama, one in Colombia and one in Nicaragua-Costa Rica. However, the routes of the most easily excavated conventionally constructed canal, and of the shortest nuclear canal, are all located in Panama. After the investigation began, another route in Panama was added. Routes 14 and 10 are in or near the Canal Zone and would be excavated by conventional methods. Route 17 is in the Darien Region of Panama, approximately 100 miles east of the present canal, and would be excavated primarily by nuclear explosives utilizing conventional excavation for about 20 miles of its length.

In addition, the Commission has explored two other possibilities. One would be the construction of a third and larger lane of locks to augment the present canal. The second is the possibility of a United States-Colombian-Panamanian canal on Route 23.

If a canal were constructed on Routes other than Route 14, there would be engineering advantages to maintaining the lock canal in standby condition for an indefinite period. This arrangement has been recommended in Annex V, *Study of Engineering Feasibility.*

Terminal Lake–Third Lane of Locks

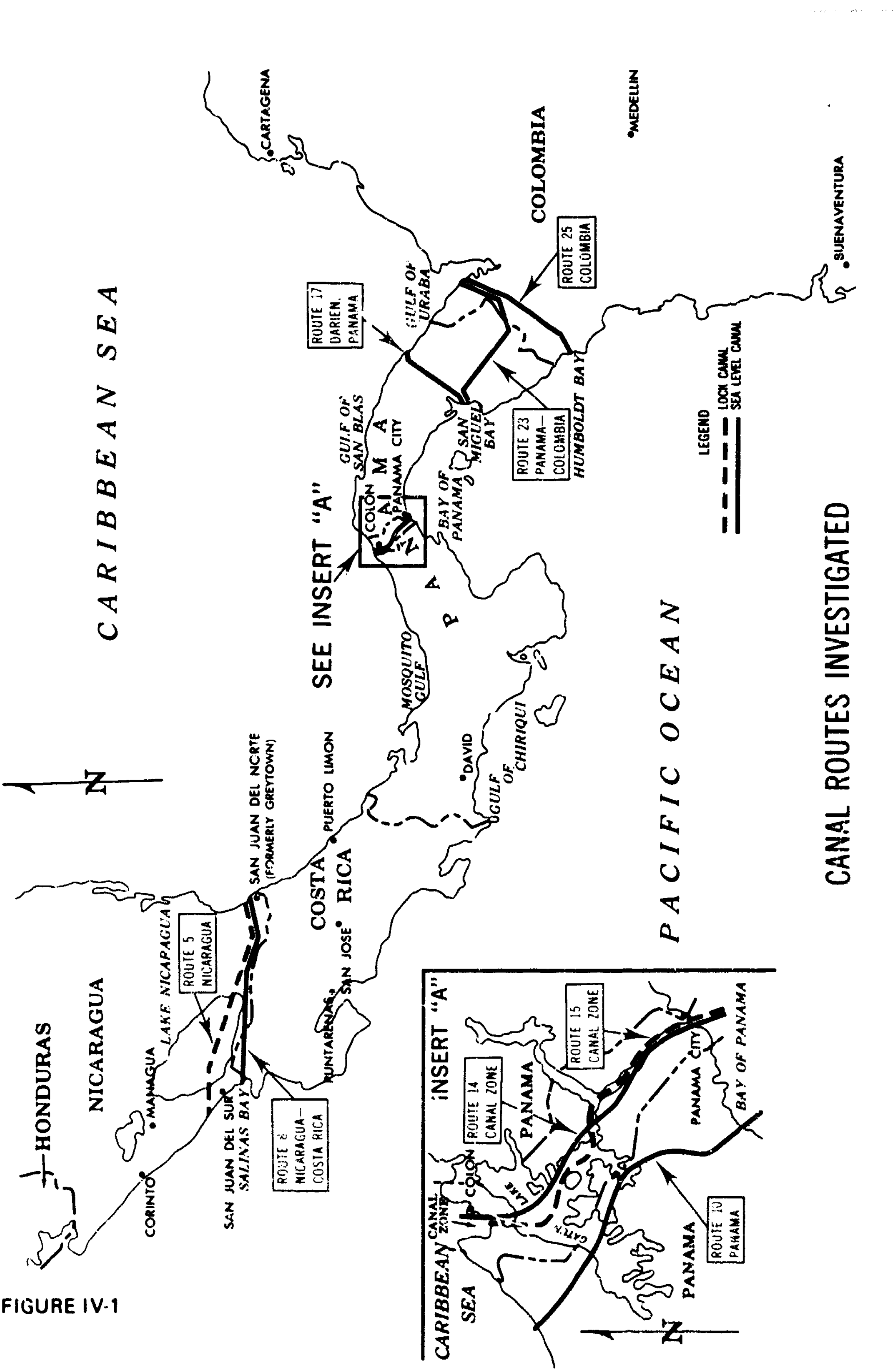
There have been many proposals for increasing the capacity of the present canal. The most promising are variations of two basic plans: the Third Locks Plan, and the Terminal Lake Plan. The former was initiated in 1939 and discontinued during World War II after expenditure of approximately $75 million on excavations for larger locks adjacent to the existing locks. The new locks would have been 1,200 feet long, 140 feet wide, and 50 feet in depth over the sills. Such locks would accommodate vessels of up to approximately 110,000 DWT and would increase the canal's capacity to about 35,000 annual transits.

The Terminal Lake Plan would consolidate the Miraflores and Pedro Miguel Locks on the Pacific side, raising Miraflores Lakes to the level of Gatun Lake. In the process a third lane of locks would be added on both the Atlantic and Pacific sides. This plan has the advantage of providing an anchorage area above the Pacific locks which would eliminate navigational hazards now encountered in that area.

The proponents of the third lane of locks concept believe it has a major political advantage, namely, that it can be built under the provisions of existing treaties. The Panamanians oppose this view, although they agreed in a 1939 exchange of notes clarifying the 1936 Treaty that the United States could undertake additional construction–and we, in fact, did.

The limitations of the third lane of locks solution are significant. A third lane would provide approximately 8,000 additional annual transits.* At the projected traffic growth rates, this new capacity could be exceeded as early as 2000, and additional expansion would presumably be needed. The third lane would meet traffic requirements through that year at the least cost to the United States, but this is its only major advantage in comparison with the sea-level canal alternatives. Lack of sufficient water from Gatun Lake for additional locks poses a limitation that can be met by costly pumping of sea water. This solution

*From a base point of 26,800 annual transits, the maximum capability of the present canal.



CANAL ROUTES INVESTIGATED

FIGURE IV-1

would cause Gatun Lake to become brackish. Recirculation of fresh water used in the locks is another solution, but one which is more costly still.

The third locks solution creates an additional requirement for skilled operating employees and continues the existing lock canal's inherent need for a large number of United States management personnel and technicians. While this can be overcome in time through internal training and promotion of Panamanians, the rapidly expanding Panamanian economy would compete for the same skills.

Route 14

Route 14 runs generally along the existing lock canal alignment and lies entirely within the Canal Zone. Its land cut is 33 miles, and its Atlantic and Pacific approaches, leading from the land cut to water 85 feet in depth, total 21 miles. The estimated construction cost is $3.0 billion.

The trace of Route 14 is generally east of the existing canal on the Atlantic side of the Isthmus. Route 14 intersects the existing canal near the southeast end of Gatun Lake, and is generally west of it from there to the Pacific.

Panama City on the Pacific terminus and the towns of Colon and Cristobal on the Atlantic terminus are available to support the construction, operation, and maintenance effort of Route 14.

As an alternative to the trace of Route 14 through the Continental Divide, a separate divide cut would be aligned to diverge from Route 14 in the Continental Divide region. The separate Divide cut would minimize the probability that construction operations would endanger the stability of the banks of the existing canal. Further discussion of Route 14 in this Annex will refer to this separate Divide cut alignment.

Gatun Lake, which has an area of about 165 square miles, is an integral part of the existing canal. It is formed by waters impounded by Gatun Dam. Gatun Lake provides water for the lockage of ships through the existing canal and is also used for hydroelectric power and municipal water supply.

Gatun Lake would be divided by Route 14 and would require dams to protect against runoff of the lake into the sea-level canal. After construction, the most economical level for water in the lake would be at about elevation fifty-five feet, which is twenty-seven feet below its low level for operation of the existing canal. This would reduce the hydroelectric supplies available to Panama, but the absence of locks would reduce the operational requirement for electricity and eliminate the need for lockage water.

There are several construction problems of foreign policy interest associated with Route 14. One problem which is unique to Route 14 would be interference with canal traffic during construction. Route 14 would have a period of one to three months when it would be necessary to draw down from the level of Gatun Lake. This drawdown would permit the water level in the new canal to seek its final elevation at sea level. Canal closure would be announced well in advance but there would be major inconvenience to world shipping nonetheless.

The magnitude and composition of the construction force required for Route 14 also could have foreign policy implications. During the sixteen year design and construction period construction personnel would build up to over seven thousand during the fifth, sixth, and seventh years. The construction force would then taper off to about two thousand

during the fifteenth and sixteenth years. Although considerable use would be made of Panamanian labor, a large portion of the construction force would probably be United States citizens under the employ of United States contractors. The acquisition of real estate for Route 14 would not be expected to have a large dollar cost since construction would be on land within the existing Canal Zone.

The operation of a sea-level canal along Route 14 would be considerably simpler than the operation of the existing lock canal. It is estimated that about 2200 canal employees would be required, a major portion of whom at least initially would be United States personnel.

Route 10

Route 10, the Chorrera-Lagarto Route, begins at the village of Lagarto, about fifteen miles west of Colon on the Atlantic coast. It extends to the southeast across the Trinidad arm of Gatun Lake and the Continental Divide to its Pacific terminus near the town of Chorrera. Route 10 is generally parallel to the existing lock canal at a distance of about ten miles from the canal. It intersects the Continental Divide eight miles from the Pacific, where the elevation is about 430 feet above mean sea-level. The area between the Pacific Ocean and Gatun Lake is generally rolling country while the area between Gatun Lake and the Atlantic is lower but quite rugged.

The area traversed by most of Route 10 is relatively undeveloped. The coastal towns are accessible by highway but the interior roads are poor.

The overall length of Route 10 is about fifty-three miles, including ocean approaches. The cost of construction is estimated to be about $2.9 billion. The land cut of Route 10 is a little longer than Route 14 and greater excavation yardage is involved; however, Route 10 permits the use of less costly excavation methods. A larger range of choice in construction equipment is possible on Route 10 where there are no construction restraints imposed by existing structures or canal traffic.

Route 10 generally would avoid Gatun Lake, except for the Trinidad Arm and the smaller Caño Quebrado Arm. Dams along that portion of Route 10 which traverses Gatun Lake would be shorter than along Route 14. Construction and operation of Route 10 would not interfere significantly with maintenance of Gatun Lake at its present elevation, and thus would not affect the hydroelectric supply significantly.

Among the problems of foreign policy interest associated with Route 10 are those of land acquisition and the possible operation of the present lock canal and a sea-level canal as a single system.

Land acquisition problems for Route 10 would be more extensive than for Route 14. The acreage of land required for construction, operation and maintenance of a sea-level canal would not be greater in the case of Route 10 but acquisition would involve land outside of the Canal Zone at a higher unit cost. The land near La Chorrera is well-developed farming and grazing area. Canal construction would displace approximately two thousand Panamanians but would not necessitate the relocation of the town of La Chorrera. Land acquisition on Route 10 could prove to be a greater problem than on the other routes.

A canal on Route 10 would have a lesser negative economic impact on the cities than would construction on Route 17 or a canal outside of Panama. Some of the impact of closing or reducing the use of the existing lock canal would be offset by construction of new

facilities on Route 10. These facilities would probably employ about 2,200 personnel, the same number who would be employed on a sea-level canal along Route 14. The net impact would be a reduction of over two thousand operating and maintenance personnel and a proportionate decrease of about 4000 supporting personnel compared with the existing canal. The work force required to construct Route 10 would be comparable to that required for Route 14.

Operation of a sea-level canal on Route 10 in combination with the lock canal would allow at least 65,000 transits per year. Conversion of the lock canal to a second sea-level canal, a possible means of expansion, could be deferred well into the next century. Two sea-level canals could have a combined capacity of over 100,000 transits per year, a level not likely to be required for well over a century.

Route 17

The feasibility of nuclear excavation is the key to the feasibility of Route 17. The two issues interact, since not only does Route 17 mean nuclear excavation–but nuclear excavation entirely within Panama must mean Route 17.

The route is located in the Darien isthmus of Panama, where Balboa crossed in 1513. The route connects Caledonia Bay, an arm of the Caribbean Sea, and the Gulf of San Miguel on the Pacific Ocean. The Continental Divide is about ten miles from the Atlantic side of Route 17. Peaks rise well over a thousand feet. A crossing has been located at an elevation of about 1000 feet. The length is about forty-nine miles of land cut plus almost 30 miles of ocean approaches.

In the Darien region there is a complete absence of roads or railroads which could be used to support the construction of a canal along Route 17. This problem would be alleviated by construction of the Inter-American Highway through the Darien Gap, a project now in advanced stages of planning. The principal means of transportation into the interior have been by boat, foot, or aircraft.

The estimated cost of Route 17 is about $3.1 billion, assuming nuclear construction to be feasible. This includes the cost of excavating about 20 miles by conventional means because of potential slope stability problems in the area. The cost of conventional excavation of the entire route would be prohibitively great, approximately $6 billion.

Lands affected, some privately owned, are largely undeveloped at present. There are squatters living by subsistence farming throughout the area.

Route 17 offers several advantages for construction compared with the other routes in Panama. These advantages derive primarily from the distance separating Route 17 from the existing canal. There would be no interference imposed by Route 17 construction on the traffic in the existing canal. The size of nuclear charges would be limited to preclude significant damage due to ground shock to built-up areas such as Panama City.

The magnitude of the construction force would be less for Route 17 than for Routes 10 and 14. During the 16-year design and construction period construction personnel would build up from about one thousand the first year to four thousand during the second and third years. The construction force would average two thousand personnel during the last four years of work.

There are construction problems of foreign policy interest associated with Route 17. Danger to and disruption of lives must be taken into consideration. It would be necessary to

evacuate inhabitants of the immediate area of the nuclear excavation reaches on Route 17 during construction. This exclusion area is one of the most primeval and sparsely populated in Central America. The population within the nuclear exclusion area is estimated at 43,000, mainly tribal Indians and others living in small settlements or as migrants. Nuclear excavation would yield a 1,000-foot wide channel capable of handling the largest potential traffic.

Route 23 (Figure IV-2)

On September 14, 1969 there was a joint declaration by Panamanian Foreign Minister Nander Pitty and Colombian Foreign Minister Alfonso Lopez Michelsen recognizing a common interest in a sea-level canal along Route 23, and in other possible routes as well.

Route 23 follows Route 25 along the Atrato River in Colombia about 30 miles. Then it turns northwest into Panama and enters the Pacific at the Gulf of San Miguel near the Pacific end of Route 17. Its total length is 146 miles including 27 miles of ocean approaches. The highest elevation encountered is about 450 feet as compared to 930 feet on Route 25 and 1000 feet on Route 17. The 1947 studies found many technical and cost disadvantages due to length and excavation volume, and excessive angularity.

Route 23 would contribute greatly to the growth of an isolated and under-developed area of the country and would be consistent with Colombia's moves toward regionalism and close cooperation with its neighbors.

All Panamanian arguments against excavating a canal far from present population centers are applicable. Also, Panama would have to share benefits from the canal with still another country.

DEFENSE CONSIDERATIONS

The defense of a sea-level canal will pose political problems regardless of the country in which it might be located. In Panama the political problem of defending a new canal differs for each of the three routes being studied. There follows a discussion of the problems of defense of each route.

Route 14

Defense of Route 14 would probably cause the least problems in the short run. The United States base complex for this route is already in existence, and there would not be the reaction associated with the initial introduction of a foreign military presence

Over the long run the defense forces for Route 14 have the disadvantage of being very much in the Panamanian eye. Major military installations are located in the immediate vicinity of Panama's two largest urban centers. Panama City and Colon. As the United States presence in Panama diminished under the new lock canal treaty, and even more so under a sea-level canal administration, a continued major United States military presence, so close to urban centers, could attract criticism.

The local defense troop requirements for a sea-level canal along Route 14 are currently estimated at somewhat less strength than presently required in the Canal Zone.

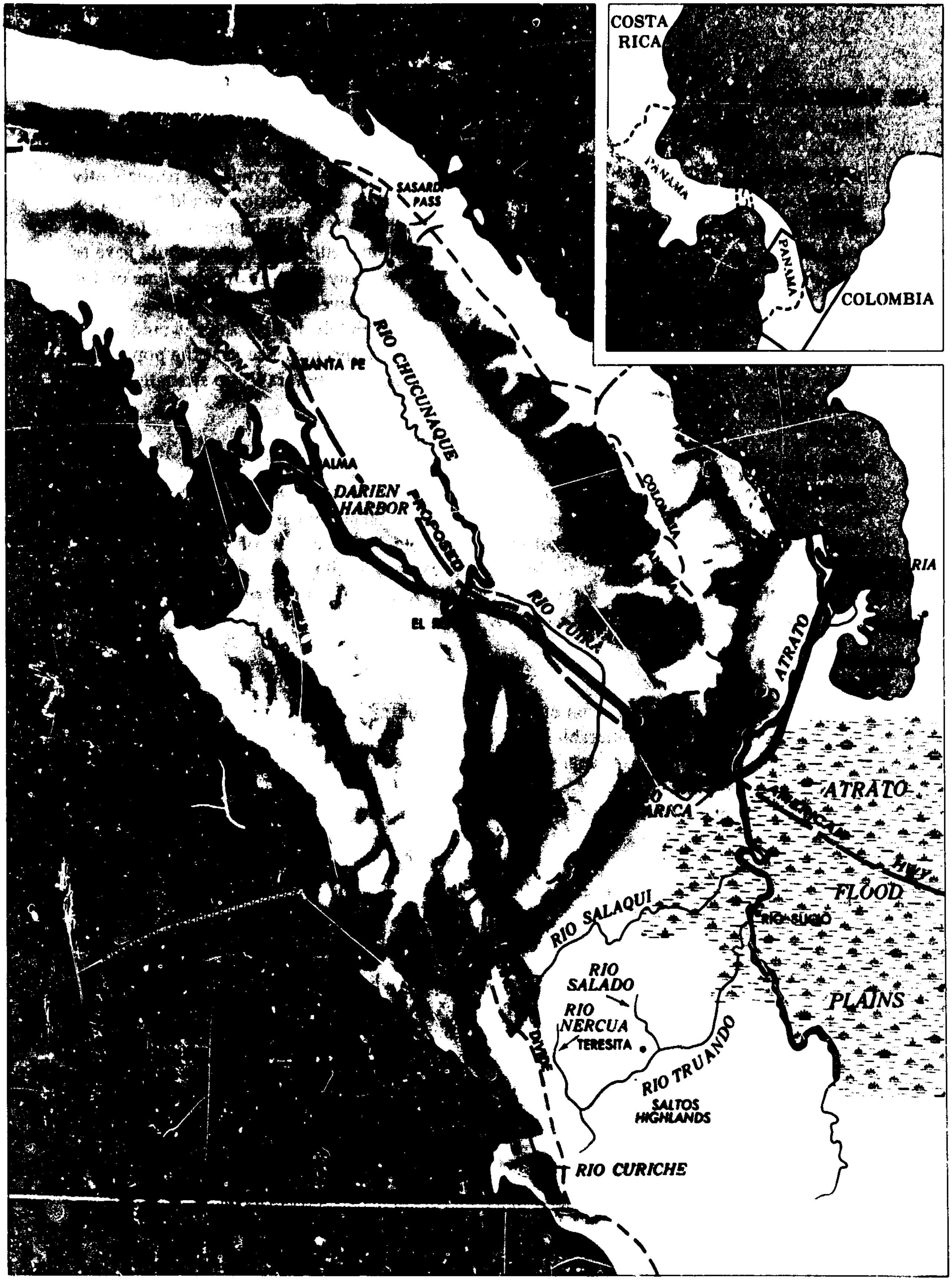


FIGURE IV-2

ROUTE 23
PANAMA-COLOMBIA BORDER AREA

SCALE IN MILES
5 0 5 10 15 20 25 30 35
DEPTHS IN FATHOMS

Route 10

The considerations which apply to the defense of Route 14 are in general applicable to Route 10. Defense forces would be approximately the same and could be permanently stationed in the present Zone base complex. New military construction would be slightly larger than for Route 14, or in the vicinity of $13 million. It would be necessary to assure access to the Canal Area. To do this, a minor United States military presence would have to be established in a new area of Panama. This would probably be more troublesome on the Pacific than the Atlantic side since the Pacific side is a well-developed farming area.

Since the base structure would remain almost completely intact, there would be no lessening of the problem associated with a large United States presence near the population centers of Panama City and Colon. There would be some reduction in troop strength needed for defending the less vulnerable sea-level canal.

Route 10 Operated with the Lock Canal

The defense advantages of a sea-level canal on Route 10 have been discussed above. These advantages would be somewhat greater in the canal system as envisioned; the present canal would be usable if the sea-level canal were blocked. Defense of the standby canal should cause no major additional problems. The existing military bases are already suitably sited, and the forces planned for the defense of Route 10 could, with acceptable risks, provide protection for the standby facilities.

Route 17

All but twenty miles of a canal on Route 17 would be constructed with nuclear devices. This canal would be less vulnerable to attack than any conventionally constructed canal, primarily because the nuclear canal's greater depth would make it relatively invulnerable to blockage by the sinking of ships.

Route 17 would require considerably more military construction than either Routes 14 or 10. Estimated cost of construction, including troop facilities, the road net, and high performance aircraft landing fields is approximately $125 million. The forces required would be substantially the same as for Routes 14 or 10.

Route 23

The defense of a sea-level canal constructed on Route 23 would raise complicated questions for the United States, Panama and Colombia. Route 23 would be the most difficult to defend of all the routes under construction due to its greater and winding length. Canal defense requirements would thereby be more complex. Military construction costs would also run higher than for the other routes.

Terminal Lake–Third Lane of Locks

One of the greatest disadvantages of th third lane of locks solution is that it would not reduce materially the vulnerability of the lock canal to long-term interruption by sabotage or military attack.The inability to transit the United States Navy's aircraft carriers and the weaknesses of the locks and of the high level lake would remain unchanged.

ECONOMIC CONSIDERATIONS

Economic Impact of the Canal on Panama

Activities associated with the Panama Canal along with United States military activities in the Canal Zone have played a major role in the economic development of the Republic. The Republic itself has a private enterprise economy within a land area about 480 miles from east to west, which varies in width from 30 to 120 miles. Its population is presently estimated at 1.4 million, of whom 48% live in towns containing 1,500 inhabitants or more. This is the smallest population of any independent country in Central America with one of the lowest population densities. About 85% of the population is literate.

The land area of Panama is divided into two almost equal parts by the ten-mile-wide Canal Zone. Although the Zone is under the jurisdiction of the United States Government, the Republic of Panama has free transit rights across it without customs or other restrictions. Almost all of the nonagricultural activity of the country takes place in the Colon and Panama City areas, adjacent to the Zone. David, the third largest city, is the center of Panama's principal agricultural and cattle area. The area to the east of the canal consists primarily of undeveloped swamp, forest, and some farm land.

The Panamanian monetary system is based on the United States dollar to which the Balboa is pegged at a one to one ratio. The monetary agreement of 1904 between the United States and Panama provides the basis for the quantity and content of the Panamanian currency. Although prices and accounts in Panama are stated in Balboas, issue of the Balboa is limited to the silver Balboa and subsidiary coins. United States currency circulates freely and is the principal medium of exchange. Banks hold dollars to satisfy legal reserve requirements. Thus, both government expenditures and domestically financed investment expenditures are closely tied to the amount of foreign exchange available to the economy. The government is circumscribed in its ability to increase the money supply at its discretion to finance its own spending, except by borrowing.

Panama is greatly dependent on imported goods and has had a continuing and widening negative balance of trade. This imbalance has been covered mainly by the inflow of private capital and by external borrowing. Private investment cannot directly be expanded by domestic borrowing because the lending ability of banks depends on their dollar position. However, private investment can be expanded through external borrowing. Thus, the expansionary effects that government or private investment spending might have are limited to–and can be summarized by–the amount of external financing that can be obtained. Dollar availability is, therefore, the crucial factor in the country's economic expansion.

The canal operation and activities associated with it are by far the largest single source of dollar earnings with the total of net exports of goods and services due to the canal and United States military activities estimated by the Stanford Research Institute as comprising 66% to 75% of all earnings from the export of goods and services. United States military activities in the Zone account for 35% to 38% of the combined canal/military total above. Canal related earnings in turn exert a multiplier effect of between 1.13 and 2.77 on overall national income levels.

The economic impact of the canal is particularly significant in the Panama City and Colon metropolitan areas. There, employment for about 22,300 (12.5% of total employment) is provided directly by the Zone. Since the average wages of most workers in

the Canal Zone are significantly greater than the wages of the average metropolitan worker, the income of the former plays an even more important role. If the indirect effect of this direct foreign exchange input is taken into account, it is estimated that about 74% of the total employment of the metropolitan area would directly and indirectly be due to the canal.

Tables IV-1 and IV-2 provide data on gross payments and income flow directly to the Republic of Panama from the Canal Zone and on salaries and net income of non-United States citizen employees of the Canal Zone resident in Panama.

TABLE IV-1

ESTIMATED GROSS PAYMENTS AND INCOME FLOW TO THE REPUBLIC OF PANAMA FROM THE CANAL ZONE (1967 and 1968)

	(In Thousands of Dollars) 1967	1968 (preliminary)
1. Wages and salaries paid to Panamanian residents employed in the Canal Zone	$ 58,761	$ 65,109
2. Retirement and disability payments to Panamanian residents	4,479	5,508
3. Direct purchases in Panama by U.S. Government Agencies	19,402	21,090
a) Goods	13,868	16,235
b) Services	5,534	4,855
4. Purchases of goods in Panama by private organizations operating in the Canal Zone	11,342	10,000
a) Petroleum products	6,542	5,000
b) All other goods	4,800	5,000
5. Contractors' purchases in Panama of goods and services for Canal Zone projects	8,272	11,704
6. Expenditures made in Panama by residents of the Canal Zone	30,744	33,885
Sub-Total	133,000	147,296
7. Panama Canal Annuity	1,930	1,930
Total	134,930	149,226

Explanatory Notes

Item No.

1. Gross payrolls, non-U.S. citizen residents of Panama employed in the Canal Zone by U.S. agencies, contractors, and private organizations (e.g., shipping agents,

TABLE IV-1 (Cont'd.)

clubs, churches, oil companies, banks, employee associations). Does not include wages of Panamanian residents employed by private individuals and households; the latter are included in the estimates given in Item No. 6 below.

2. The sum of disability and relief payments to Panamanians by Panama Canal Company/Canal Zone Government and retirement checks distributed to Panamanians by United States Embassy, Panama.
3. Aggregate amounts of goods and services purchased in Panama by U.S. agencies operating in the Canal Zone as reported quarterly by the respective agencies.
4. (a) Figure supplied by Office of Comptroller General of the Government of Panama.

   (b) Estimated on the basis of sample surveys.
5. Estimated on the basis of sample surveys.
6. Expenditures for goods and services purchased in Panama by U.S. and non-U.S. citizen residents of the Canal Zone including wages paid Panamanian residents employed in the Canal Zone by private individuals and households. Estimated on the basis of sample surveys.

TABLE IV-2

SALARIES AND NET INCOME OF NON-U.S. CITIZEN EMPLOYEES OF THE CANAL ZONE RESIDENT IN PANAMA (1967 and 1968)

	(In Thousands of Dollars)	
	1967	1968 (preliminary)
Gross Salaries Received From	$58,761	$65,109
U.S. Agencies	53,123	58,338
Contractors	2,278	2,991
Private Organizations	3,360	3,780
Less	7,540	8,048
Deductions for retirement funds	3,160	3,448
Expenditures for:		
a) Hospital Fees	1,158	1,286
b) Transportation and Service Center Fees (1)	3,222	3,314
Net Income	51,221	57,061

NOTES:

(1) Expenditures at service centers represent authorized purchases of small articles, such as meals, candy, chewing gum, tobacco and similar articles.

Data do not include the earnings of non-U.S. citizen employees resident in the Canal Zone.

OTHER ECONOMIC OPPORTUNITIES

Normal Economic Development

Panama's economic growth for the period 1961-68* shows an average annual increase in the Gross Domestic Product (GDP) of 7.5%–the highest rate achieved by any country in the hemisphere. The steadily rising demand for goods and services by the Canal Zone and to a lesser extent by the Colon Free Zone has played a key role in stimulating domestic investment and export-oriented activities. During the period 1960-68, earnings from the Canal Zone increased on the average by 10.1% per annum. Thus the importance of the Canal Zone and related activities to the continuing growth of Panama's economy is unquestioned.

Future growth, however, will also depend to an important extent on three additional factors:

(1) Panama's ability to maintain and increase its present exports to areas other than the Canal Zone;
(2) the promotion of new exports and services; and
(3) the maintenance of high levels of domestic investment.

(1) Ability to Maintain and Increase Present Exports:

Bananas: Bananas are Panama's principal export, accounting in 1968 for 54% of the country's visible exports. Assured of foreign markets and favorable prices, banana production has grown at a yearly average of 12% during the 1961-68 period. The Chiriqui Land Company, a United Fruit Company subsidiary which is the principal banana exporter, expanded its area of activities substantially in 1966 and is now considering doubling its operations by 1973.

Petroleum Products: Since the beginning of operations of the petroleum refinery in 1962, exports of refined petroleum products to ships transiting the canal as well as to the world market have achieved increasing importance. In 1968 such exports amounted to about 20% of total exports. The refinery increased its capacity in 1968, which allows it to increase exports further. In addition, construction of a multi-million dollar petrochemical complex is under active consideration. The new plant will greatly expand the export potential of Panama's petrochemical industry. Panama has no known petroleum resources and all crude petroleum is imported.

There has also been discussion in Panama of constructing a transisthmian pipeline to transport bulk shipments of crude petroleum from tankers on the Pacific side of the Isthmus to ones on the Atlantic side.

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*For consistency, all figures used in this section end with calendar year 1968.

Shrimp: Exports of shrimp have risen steadily between 1963-68, though at a decreasing rate of growth, and in 1968 constituted about 11% of total exports. The slow growth was due to supply limitations rather than a lack of markets, and the Secretariat of the Inter-American Committee of the Alliance for Progress (CIAP) has recommended that possibilities be studied to increase the catch of shrimp.

Sugar: In 1968 sugar exports amounted to 32 million tons, virtually equal to the United States sugar quota for Panama. Sugar at the present time constitutes Panama's fourth most important export, and in 1968 amounted to about 5% of total export.

(2) Promotion of New Exports and Services:

Tourism: Tourism is an important earner of foreign exchange, accounting in 1968 for about 23% of Panama's net foreign exchange earnings in its balance on goods and services. In 1968 travellers from the Canal Zone accounted for more than two-thirds of these earnings, but in previous years earnings from foreign countries more nearly equalled the tourist earnings from the Canal Zone. At the present time Panama has an estimated 100,000 visitors a year, but plans are under way to double this number within the next few years. It is considered that the estimated 250,000 transit passengers through Panama each year constitute a good potential for achieving this goal, and projects are under way to expand and improve services at Tocumen International Airport, increase the country's hotel room capacity and develop new tourist attractions.

Meat and Livestock: In 1968 the value of livestock output amounted to $25 million and represented about 17% of Panama's agricultural production. Exports of meat and livestock amounted to only $1.7 million. With the expansion of livestock production, which increased by 50% between 1961 and 1968, possibilities for a gradual rise in exports appear good. The CIAP Secretariat estimates that by 1971 exports of meat products and livestock will amount to $4 million.

Fishmeal: The CIAP Secretariat projects a rapid growth of exports of fishmeal, reaching $8 million in 1971.

Citrus Products: Exports of citrus products are a new addition to Panama's foreign exchange earnings. Citricos de Chiriqui, S.A., which has been preparing its plantations and other facilities since 1964, was scheduled to begin exporting fruit and juice in 1968. However, technical problems continue to thwart production and it appears increasingly unlikely that CIAP Secretariat projections for exports amounting to $4 million by 1971 will be met.

(3) Maintenance of High Levels of Domestic Investment:

Domestic investment levels as a percentage of the Gross Domestic Product hovered around 20% per annum for the 1961-68 period. Most of this high rate of productive activity in the economy was generated by the private sector, which in 1968, for example, accounted for 82% of total investment outlays. The investment boom of the 1960's resulted from a high rate of domestic savings, supplemented by capital inflows from abroad, mostly on private account. Since 1968 the public sector has sustained the high investment level. On the basis of recent government plans and statements, it may be assumed that public sector investments will continue to increase rapidly over the next few years.

Darien Highway

The Darien Gap Highway is the last unfinished link of a Pan American Highway network connecting the South American continent with Central and North America. The project has been under study for some 15 years by the Darien Sub-Committee of the Pan American Highway Congress. The Subcommittee has prepared estimates for the construction of 401 kilometers of road, 320 of which are in Panama and 81 in Colombia. The currently estimated cost of an asphalt-paved road is $150 million over a five-year construction period. President Nixon has indicated United States willingness to provide a substantial portion of the funding for the project and an appropriation is now being sought for this purpose.

No detailed study has yet been made of the implications for the Panamanian economy of constructing the Darien highway. Its value would obviously be enhanced were it to serve as a link to a canal on Route 17.

Various reports, however, describe the Darien region as rich in commercially exploitable timber resources, suitable for banana plantations, and potentially attractive for international tourism. As to the economic impact of the construction as such, we believe it would be highly favorable.

Mineral Deposits

Simultaneous announcements from the United Nations Development Program and the Government of Panama in April 1968 revealed the discovery of copper and molybdenum in Panama in sufficient quantities to justify more extensive exploration efforts. Estimates of the extent and value of the initial find in the Donoso District of the Province of Colon vary, with optimists putting its potential in the "multi-million dollar range," while some mining officials contend they will need considerably more information before they decide if the copper is worth the expense of digging it out. The area of the discovery is one of intense rainfall and tropical growth, about 15 miles from the Caribbean Sea. Thorough exploration of the site is expected to cost $5-$10 million.

Additional copper discoveries were announced in a region adjacent to the original find in January 1969. The United Nations and the Panamanian Department of Mineral Resources have extended the original exploration and have announced approval of a second project for the central range. While these minerals could prove to be a resource capable of supplementing the canal in importance to Panama, their worth and exploitability remain to be established.

Regional Economic Integration

One way of broadening the economy's base would be for Panama to associate itself with one of the regional trading groups, such as the Andean Group of the Latin American Free Trade Area (LAFTA), the Central American Common Market (CACM) or the proposed Caribbean Trading Group (CARIFTA).

Three major obstacles to Panama's entry into a regional market are: (a) the strong attraction to foreign imports of Panama's higher-income, commercial market; (b) the potential loss of some benefits from Panama's predominant position in the canal market; and (c) the Panamanian monetary system.

UNITED STATES PRIVATE INVESTMENT AND TRADE WITH PANAMA

Panama has continued to attract a share of direct United States private investment in Latin America disproportionate to its population and size. Of the approximately $13 billion total of United States private investment in 19 Latin American republics in 1968, $922 million was located in Panama. The three major areas of direct United States investment are local trade, agriculture and petroleum refining. There are considerable individual investments in telecommunications, electric power, and banana plantations. In addition, more than 200 United States firms use the Colon Free Trade Zone for manufacturing, processing, warehousing and trans-shipping goods to Latin America. United States interests in the petroleum, mining, power, and hotel industries will provide areas for continuing direct private investment in the future.

The United States is Panama's principal trading partner. In recent years the United States has taken about 60% of Panamanian exports and has supplied about 40% of its imports. Bananas, shrimp, and refined petroleum products are the principal exports. In real terms, the value of trade with the United States reflects the republic's overall excess of imports over exports, with Panama's exports to the United States totalling $73.1 million and her imports from the United States reaching $93.5 million in 1968.

UNITED STATES ECONOMIC ASSISTANCE TO PANAMA

The Agency for International Development's technical and economic assistance to Panama since the inception of the Alliance for Progress (FY 1961-FY 1969) totals $137 million, averaging about $15.2 million per year. About $35 million of this amount has been in grants, the rest in long term development loans. On a per capita basis, this represents one of the highest outlays of United States assistance in the world.

ECONOMIC IMPACT ON PANAMA OF ALTERNATIVE ROUTES

The principal economic issues that would be created for Panama by the construction and operation of a sea-level canal are: (a) inflationary pressures during the construction period of a sea-level canal in Panama; (b) deflationary pressures when a sea-level canal becomes operational; and (c) the shift of certain activities from the Panama and Colon areas to the Darien Region if a sea-level canal at Route 17 were opened. Following is a summary of the findings of the Stanford Research Institute's study of economic implications of alternative sea-level canals as they apply to these issues. These findings are summarized in Figure IV-3 and IV-4 and Tables IV-3 and IV-4. For analytical purposes it was assumed that a sea-level canal or a third lane of locks would commence operations in 1985.

(a) Inflationary Pressures During Construction

The construction of a sea-level canal combined with increased benefits from the existing canal* would have a limited inflationary impact on the economy. In peak construction years, the levels of Gross Domestic Product (GDP) relative to the levels without construction (but with increased benefits from the existing canal as contemplated in the 1967 treaty drafts) are estimated as follows:

Route	GDP	Employment
10	+10.5%	+7.6%
14	+10.3%	+8.1%
17	+11.6%	+9.5%
3rd Locks	+ 6.3%	+6.2%

Given the normal "slack" existing in a country such as Panama, the impact of construction expenditures would have a buoying effect which could be handled without undue inflationary pressure. However, there is good reason to believe that something less than the normal amount of slack will exist during the peak construction periods. The rapid increase in GDP which occurred in the 1960's is expected to continue into the 70's. The foreign exchange earnings resulting from construction as well as additional earnings from any new treaties would have a multiple effect on GDP. Even this inflationary pressure, however, will tend to dissipate itself in the form of increased imports because of the lack of barriers to trade in the economy.

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*The Stanford Research Institute based its projections of revenues from the existing canal on the assumption that provisions such as those contained in the 1967 treaty drafts would be yielding increased revenues to Panama.

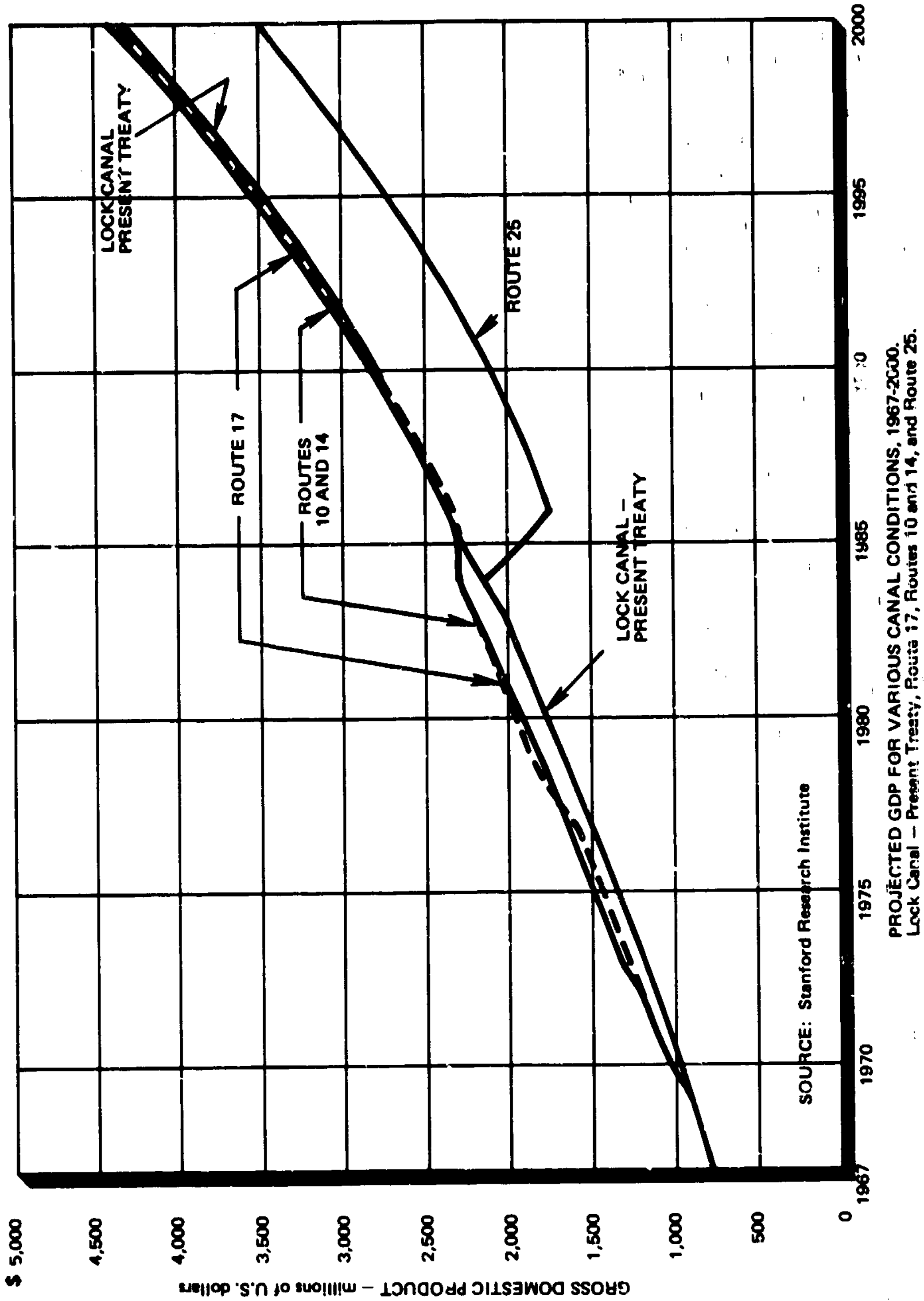
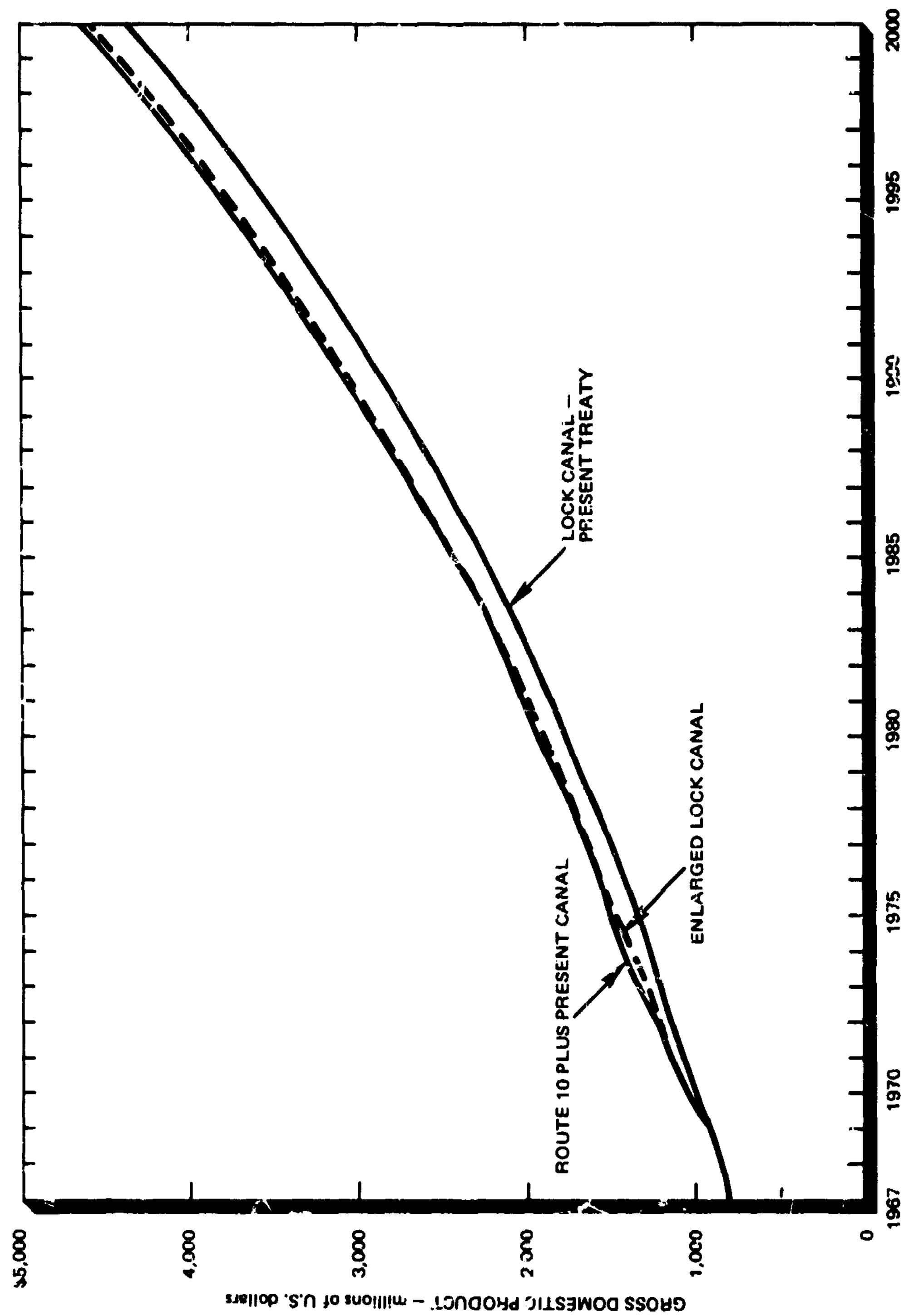

PROJECTED GDP FOR VARIOUS CANAL CONDITIONS, 1967-2000.
Lock Canal – Present Treaty, Route 17, Routes 10 and 14, and Route 25.
SOURCE: Stanford Research Institute
GROSS DOMESTIC PRODUCT – millions of U.S. dollars
$ 5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1967
1970
1975
1980
1985
1995
2000
LOCK CANAL
PRESENT TREATY
ROUTE 25
ROUTE 17
ROUTES
10 AND 14
LOCK CANAL –
PRESENT TREATY

FIGURE IV-3



SOURCE: Stanford Research Institute.

PROJECTED GDP FOR VARIOUS CANAL CONDITIONS, 1967-2000. Lock Canal — Present Treaty, Route 10 Plus Present Canal, and Enlarged Lock Canal.

FIGURE IV-4

The important constraint in Panama is the effective size of the labor force. In boom periods people are drawn into employment who were never officially considered part of the labor force. Half of Panama's population is still in the rural sector; one would imagine a very large pool of usable labor to exist there. Taking the potential as well as officially projected labor forces into account, there would probably be sufficient manpower available to meet not only the construction needs, but also the needs of a greatly expanding domestic economy. It should be noted, however, that the labor force as officially projected would not itself be sufficient to meet these demands fully.

(b) Deflationary Pressures when Operation Begins

The opening of a sea-level canal would impose very slight deflationary pressures as compared to levels during construction in the cases of Routes 10, 14 and 17. If the sea-level canal were operated in Colombia on Route 25, there would be a drastic reduction of GDP in Panama. The opening of an enlarged lock canal, or of a canal system including the sea-level canal on Route 10, would actually provide higher levels of income than existed during construction.

GDP levels, once a sea-level canal is in operation in Panama, would, except as noted above, tend to return from the abnormally high levels during construction to a level much closer to that which would prevail with the lock canal. In most operational years GDP would be greater than it would be with the lock canal.

In the case of either Routes 10 or 14, GDP might be about $16 million per year less for the three years immediately following completion of construction than GDP would have been with a continuation of the lock canal. Over the same three-year period, GDP with Route 17 would be a maximum of $29 million less per year. These decreases in GDP relative to conditions under the lock canal would all be temporary and would amount to only one percent or less of the total GDP.

For the enlarged lock canal the excess of GDP relative to the projection without a new canal ranges from about $140 million in 1985 (6.2%) to about $252 million in the year 2000 (5.8%). For a canal system utilizing Route 10 and the lock canal the excesses range from about $143 million in 1985 (6.3%) to about $228 million in the year 2000 (5.2%). Employment levels would tend to follow the same patterns of change. These predictions assume that a sea-level canal would be accommodating greater traffic than a lock canal which would have reached capacity in 1985.

If a sea-level canal were operated in Colombia along Route 25, Panama's GDP is predicted to drop about 26% below the projected GDP under the present lock canal. A very significant lower level of employment would occur if the canal were to be located in Colombia. It is estimated that the employment level in Panama would be 33% lower than it would be with a continuation of the existing lock canal alone, assuming that there are no efforts by the Panamanian government beforehand to compensate for the impact.

(c) Economic Dislocation Caused by Route 17

The total employment level of the Republic is estimated to be about 1.2% lower with a canal on Route 17 than that without a sea-level canal. It would be about 13% lower in the

TABLE IV-3

SUMMARY OF PROJECTED CHANGES IN PANAMANIAN EMPLOYMENT BY THE PCC/GOVERNMENT (ADMINISTRATION) AND U.S. MILITARY AND IN FOREIGN EXCHANGE* RESULTING FROM THE PROPOSED NEW TREATIES AND A SEA-LEVEL CANAL

(Income in Millions of Dollars at Current Market Prices)

	Sea-Level Canal Tonnage (millions)§		Route 10					Route 14					Route 17					Route 25				
				Foreign Exchange*					Foreign Exchange*					Foreign Exchange*					Foreign Exchange*			
Year	Low Estimates	High Estimates	Employment† (000's)	Direct ‡	Royalty	Other	Total	Employment† (000's)	Direct ‡	Royalty	Other	Total	Employment† (000's)	Direct ‡	Royalty	Other	Total	Employment† (000's)	Direct ‡	Royalty	Other	Total
1967	93	93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1968	98	98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1969	105	105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1970	111	111	-0.1	6	17	1	24	-0.1	6	17	1	24	-0.1	6	17	1	24	0	0	0	0	0
1971	117	118	-0.4	9	19	3	31	-0.4	9	19	2	30	-0.4	9	19	2	30	0	0	0	0	0
1972	124	126	-0.8	14	22	4	40	-0.8	14	22	3	39	-0.8	14	22	2	38	0	0	0	0	0
1973	130	134	-0.9	21	25	39	85	-0.9	21	25	5	51	-0.9	21	25	3	49	0	0	0	0	0
1974	136	142	-1.8	19	28	53	100	-1.8	19	28	49	96	-1.8	19	28	7	54	0	0	0	0	0
1975	142	150	-2.2	16	31	52	99	-2.2	16	31	60	107	-2.2	16	31	10	57	0	0	0	0	0
1976	148	158	-2.0	15	33	48	96	-2.0	15	33	53	101	-2.0	15	33	12	60	0	0	0	0	0
1977	154	168	-1.9	14	35	45	94	-1.9	14	35	45	94	-1.9	14	35	13	62	0	0	0	0	0
1978	158	178	-1.9	13	37	45	95	-1.9	13	37	40	90	-1.9	13	37	67	117	0	0	0	0	0
1979	164	188	-1.9	11	39	44	94	-1.9	11	39	40	90	-1.9	11	39	92	142	0	0	0	0	0
1980	168	199	-1.7	10	42	45	97	-1.7	10	42	50	92	-1.7	10	42	85	137	0	0	0	0	0
1981	172	210	-1.7	9	44	38	91	-1.7	9	44	36	89	-1.7	9	44	70	123	0	0	0	0	0
1982	176	218	-1.7	8	46	39	93	-1.7	8	46	37	91	-1.7	8	46	66	120	0	0	0	0	0
1983	179	219	-1.6	8	46	37	91	-1.6	8	46	33	87	-1.6	8	46	54	108	0	0	0	0	0
1984	183	220	-1.7	8	46	33	87	-1.7	8	46	28	82	-1.7	8	46	44	98	0	0	0	0	0
1985	186	240	-4.3	-20	51	3	34	-4.3	-20	51	3	34	-5.0	-24	51	-1	[illegible]	-8.7	-88	-2	-80	-170
1986	190	258	-6.3	-43	55	-4	8	-6.3	-43	55	-4	8	-7.4	-52	55	-6	-3	-17.3	-204	-2	-147	-353
1987	194	276	-6.3	-46	58	-4	9	-6.3	-46	58	-4	9	-7.4	-55	58	-6	-2	-17.3	-211	-2	-148	-361
1988	198	294	-6.2	-50	63	-3	10	-6.2	-50	63	-3	10	-7.4	-58	63	-5	-1	-17.3	-218	-2	-151	-371
1989	202	314	-6.2	-53	67	-3	11	-6.2	-53	67	-3	11	-7.4	-62	67	-5	0	-17.3	-225	-2	-156	-383
1990	206	329	-6.2	-54	70	-3	13	-6.2	-54	70	-3	13	-7.4	-64	70	-5	1	-17.3	-233	-2	-160	-395
1991	210	345	-6.2	-57	74	-2	15	-6.2	-57	74	-2	15	-7.3	-66	74	-5	3	-17.4	-241	-2	-164	-407
1992	214	361	-6.2	-58	77	-2	17	-6.2	-58	77	-2	17	-7.3	-68	77	-4	5	-17.4	-249	-2	-168	-419
1993	218	377	-6.1	-59	81	-2	20	-6.1	-59	81	-2	20	-7.3	70	81	-4	7	-17.4	-257	-2	-173	-432
1994	223	394	-6.1	-60	85	-2	23	-6.1	-60	85	-2	23	-7.3	-72	85	-4	9	-17.4	-266	-2	-176	-444
1995	227	411	-6.1	-62	88	-1	26	-6.1	-62	88	-1	26	-7.3	-73	88	-4	12	-17.4	-275	-2	-179	-456
1996	232	429	-6.1	-62	92	0	30	-6.1	-62	92	-1	30	-7.3	-74	92	-3	15	-17.5	-284	-2	-182	-468
1997	236	447	-6.1	-62	96	0	34	-6.1	-62	96	-1	34	-7.2	-75	96	-3	18	-17.5	-293	-2	-188	-483
1998	241	466	-6.0	-62	100	0	38	-6.0	-62	100	-1	38	-7.2	-76	100	-3	21	-17.5	-302	-2	-194	-498
1999	246	485	-6.0	-62	104	0	42	-6.0	-62	104	0	42	-7.2	-78	105	-3	24	-17.5	-311	-2	-201	-514
2000	251	505	-6.0	-62	108	0	47	-6.0	-62	108	0	47	-7.2	-79	108	-3	27	-17.5	-320	-2	-208	-530

*Foreign exchange attributable to the canal from the sale of goods and services. Capital inflows not included.
†Direct Panamanian employment of PCC/government (Canal Administration) and U.S. Military
‡Foreign exchange directly from PCC/government (Canal Administration) and U.S. Military
§The high tonnage estimates used in this table by Stanford Research Institute for calculating royalty payments are greater than those of the potential tonnage projection subsequently approved by the APICSC. Lower tonnages would reduce the royalty proportionately, but would have relatively little effect on other total foreign exchange estimates.
Source: Stanford Research Institute.

TABLE IV-4

SUMMARY OF PROJECTED CHANGES IN PANAMANIAN EMPLOYMENT BY THE PCC/GOVERNMENT AND U.S. MILITARY AND IN FOREIGN EXCHANGE* THAT WOULD RESULT FROM THE PROPOSED TREATIES AND CANAL ALTERNATIVES

(Income in Millions of Dollars at Current Market Prices)

Year	Canal Tonnage (millions): Present Lock Canal	Canal Tonnage (millions): Both New Alternatives	Enlarged Lock Canal: Employment (000)†	Enlarged Lock Canal: Direct‡	Enlarged Lock Canal: Foreign Exchange: Royalty	Enlarged Lock Canal: Foreign Exchange: Other	Enlarged Lock Canal: Total	Lock Canal and Route 10: Employment (000)†	Lock Canal and Route 10: Direct‡	Lock Canal and Route 10: Foreign Exchange: Royalty	Lock Canal and Route 10: Foreign Exchange: Other	Lock Canal and Route 10: Total
1970	111	111	-0.1	6	17	1	24	-0.1	6	17	1	24
1971	118	118	-0.4	9	19	2	30	-0.4	9	19	3	31
1972	126	126	-0.8	14	22	2	38	-0.8	14	22	4	40
1973	134	134	-0.9	21	25	3	49	-0.9	21	25	39	85
1974	142	142	-1.8	19	28	8	55	-1.8	19	28	53	100
1975	150	150	-2.2	16	31	37	84	-2.2	16	31	52	99
1976	159	159	-2.0	15	33	40	88	-2.0	15	33	48	96
1977	168	168	-1.9	14	35	36	85	-1.9	14	35	44	93
1978	178	178	-1.9	13	37	31	81	-1.9	13	37	45	95
1979	188	188	-1.9	11	39	29	79	-1.9	11	39	44	94
1980	199	199	-1.7	10	42	30	82	-1.7	10	42	45	97
1981	210	210	-1.7	9	44	28	81	-1.7	9	44	38	91
1982	218	218	-1.7	8	46	28	82	-1.7	8	46	39	93
1983	219	219	-1.6	8	46	25	79	-1.6	8	46	38	92
1984	220	220	-1.7	8	46	22	76	-1.7	8	46	33	87
1985	222	240	-0.4	15	51	19	85	0.1	17	51	17	85
1986	224	258	-0.4	27	55	26	108	0.1	33	55	22	110
1987	226	276	-0.3	27	59	29	115	0.2	33	59	23	115
1988	228	294	-0.3	27	63	32	122	0.2	33	63	24	120
1989	229	314	-0.2	27	67	35	129	0.3	33	67	25	125
1990	231	329	-0.2	27	70	38	135	0.3	33	70	26	129
1991	233	345	-0.1	27	74	41	142	0.4	33	74	27	134
1992	234	361	-0.1	27	77	44	148	0.4	33	77	28	138
1993	236	377	0	26	81	47	154	0.5	33	81	29	143
1994	238	394	0	26	85	50	161	0.5	33	85	30	148
1995	239	411	0.1	26	89	53	168	0.6	33	89	31	153
1996	241	429	0.1	26	92	56	174	0.6	33	92	32	157
1997	243	447	0.2	26	96	59	181	0.7	33	96	33	162
1998	245	466	0.2	25	100	62	187	0.7	34	100	34	168
1999	247	485	0.3	25	104	65	194	0.8	34	104	35	173
2000	248	505	0.3	25	109	68	202	0.9	34	109	36	179

*Foreign exchange attributable to the canal from the sale of goods and services. Capital inflows not included.

†Direct Panamanian employment of PCC/government (Canal Administration) and U.S. military.

‡Foreign exchange directly from PCC/government (Canal Administration) and U.S. military.

Source: Stanford Research Institute.

Panama-Colon metropolitan area. One reason for the lower level in the Route 17 case is that there would be a shift of about 41,600 employed persons from the metropolitan area to the Darien area. In terms of GDP the total amount of activity that would shift to the Darien region is estimated to be about $284 million. Substantial programs to mitigate the adverse economic impact on the Colon-Panama area would be required by such a shift.

The economic role of the United States military in Panama is projected by the Stanford Research Institute's study as decreasing during the operational years of a sea-level canal in Panama, although it will still be significant. It is estimated the United States military will account for about 9% of the total GDP at the time of completion of the canal, decreasing to about 7% in the year 2000, for any of the routes in Panama.

POLITICAL CONSIDERATIONS

The Panama Canal is a key element in Panama's political life. It has helped shape the structure of the country's society and set the pattern of its economy. As Panama's primary source of income, the canal largely determines the total amount of economic resources available for allocation. As the single most important stimulus to Panamanian nationalism, the canal is also a readily exploitable emotional issue. Thus, the replacement of the existing canal by a sea-level canal would be a matter of profound importance to Panama's future.

Panama's attitude toward a sea-level canal will inevitably be shaped by past experience with the existing canal. Most Panamanians are convinced that the United States has not dealt fairly with their country on the Panama Canal. In negotiating an agreement on a sea-level canal, Panama may be expected to place special emphasis on such issues as jurisdiction and economic benefits. Yet, although there are a number of potentially troublesome political problems involved in obtaining suitable new treaty terms with Panama, there are also many considerations which work in favor of United States-Panamanian agreement.

CHAPTER V

SITING A CANAL OUTSIDE PANAMA

PROBLEMS CREATED BY CONSTRUCTION OUTSIDE PANAMA

A decision by the United States to construct a sea-level canal somewhere outside Panama would confront this country with a major diplomatic and political problem with Panama. The canal is so essential to Panama's economic well-being that even the prospect of its effective removal would result in an immediate downturn in the country's growth; actual siting of the canal elsewhere would result in the collapse of the urban economy. The almost total dependence of Panama's urban centers on the canal is illustrated by the fact that nearly seventy-five percent of urban employment is related directly or indirectly to the waterway.

COLOMBIA AND A SEA-LEVEL CANAL

Discussion of Possible Routes

Route 25 (Figure V-1)

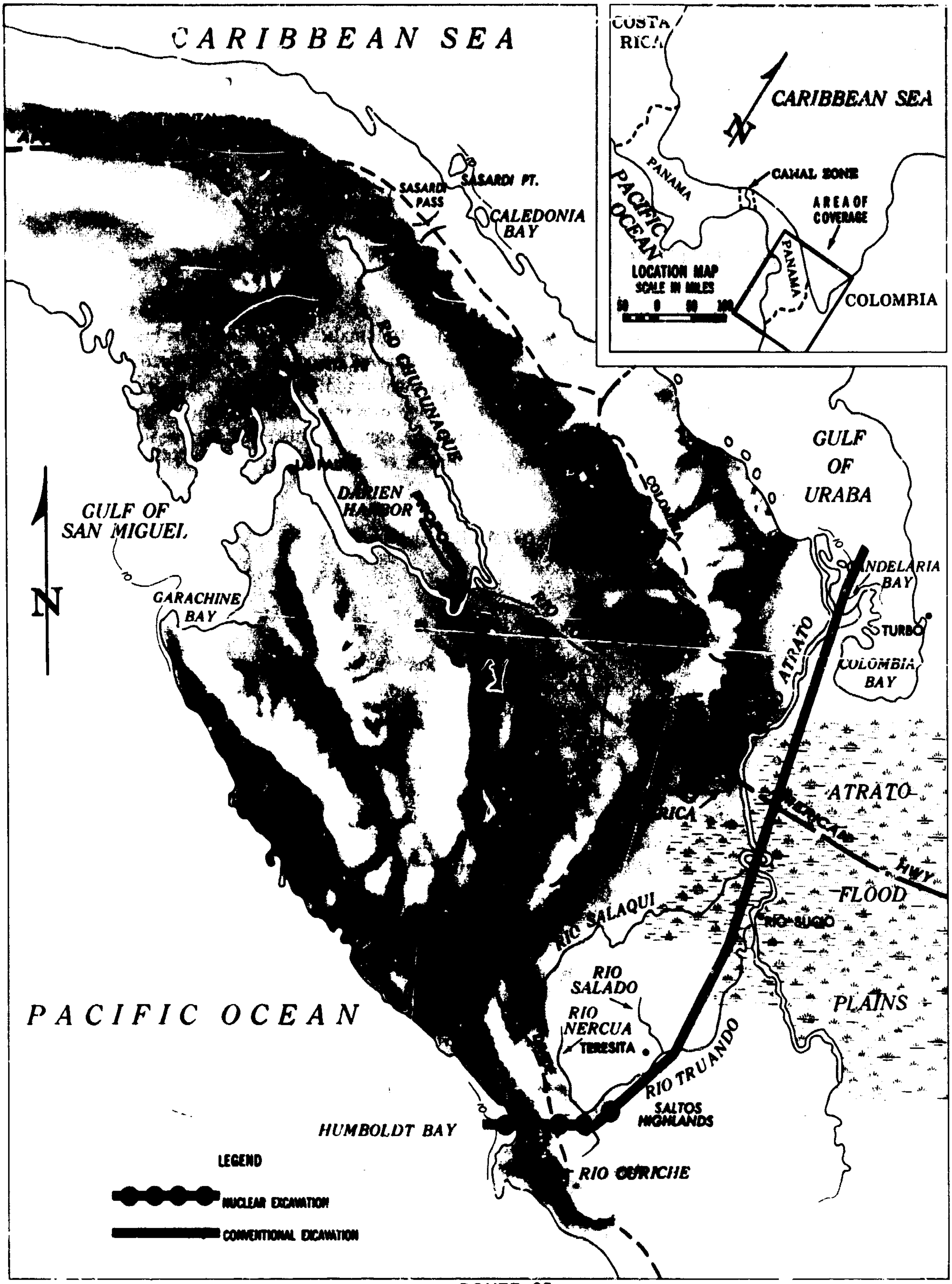
Route 25, considered for construction by a combination of nuclear and conventional methods, is located in the northwestern region of Colombia near the border with Panama. The route is approximately one hundred miles in length and, like Route 17, is located in an area remote from centers of population.

Most of Route 25 follows the northern portion of the Atrato River Valley, and would be excavated by conventional dredging techniques. The exact transition point from conventional to nuclear excavation would depend upon the nature of the geology in the upper reaches of the Truando Valley and the suitability of the soil for nuclear excavation.

The entire length of Route 25 is within the Choco Province of Colombia. The dominating terrain feature is the Atrato River, which [illegible]rallels Route 25 for about fifty miles from the Gulf of Uraba to the town of Rio Suc[illegible]ar the confluence of the Atrato and the Truando Rivers. The slope of the Atrato Valley [illegible]oor is very slight and the character of the terrain is low lying swampland with large portions of the valley floor inundated during the wet season. The route is located in one of the heaviest rainfall regions of the world. Several localities receive over three hundred inches of rain a year. Transportation facilities are extremely limited on Route 25, particularly in the mountainous area along the Pacific coast, where heavy rainfall and heavy forestation combine to make road construction very costly. The chief means of transportation along the eastern portion of Route 25 is by boat, using the Atrato River as a primary route. The swampy nature of the terrain makes road construction extremely difficult in the Atrato Valley.

The region traversed by Route 25 is largely underdeveloped. A limited amount of agricultural and lumbering operations is carried on in the area.

The Continental Divide is crossed by Route 25 near the Pacific Ocean where the elevation of the Divide is about 930 feet. The Route terminates on Humboldt Bay near the



ROUTE 25

FIGURE V-1

PANAMA-COLOMBIA BORDER AREA

SCALE IN MILES

5 0 5 10 15 20 25 30 35

DEPTHS IN FATHOMS

mouth of the Curiche River.

The estimated cost of Route 25, excavated by a combination of nuclear and conventional means, is $2.1 billion.

The primary construction problems of foreign policy interest involve the relocation of a portion of the local population and the introduction of a United States construction and operation force. As in the case of Route 17 the inhabitants are largely tribal in nature. Considerable care would have to be taken to relocate these people to assure the minimum disruption of their normal cultural and economic lives.

Design and construction would continue over a 13-year period and would entail a peak personnel requirement of about six thousand men.

Operation of a sea-level canal along Route 25 would be considerably simpler than operation of the existing canal. It would not be as simple as the operation of Route 17 because of its greater length. An estimated force of 3,000 personnel would be required for operation, a major portion of whom would not have to be United States citizens.

Route 23

Route 23, extending through Colombia and Panama, is discussed under alternative routes in Panama.

Defense Issues

The defense of Route 25 raises difficult political questions for the United States and Colombia. Canal defense requirements for United States forces would be somewhat larger than for the Panamanian routes. Military construction costs would run significantly higher than for Route 17 because more facilities would have to be located in the canal area. There would be no nearby support bases (assuming abandonment of the present Panama Canal bases). The nearest would be Puerto Rico–900 miles away.

Economic Issues

Economic benefits to Colombia from a canal would be substantial. Construction and operation of the canal would bring new income from tolls and port activities, provide increased employment and generate much needed foreign exchange earnings. Employment directly and indirectly due to the canal is estimated to range from 20,000 to 100,000 over the ten-year construction period. When this canal would be operational, employment directly and indirectly attributed to the canal would be about 200,000; this would be a significant benefit to Colombia where heavy unemployment is a major problem. The net incremental foreign exchange injection into Colombia from the canal would range from $83 million annually during the construction period to $206 million at the beginning of the operational period. This $206 million would represent about 15% of other total export earnings in 1985. Further, the canal would be certain to have an important impact on the underdeveloped Choco region in which it would be situated.

A SEA-LEVEL CANAL THROUGH NICARAGUA-COSTA RICA (Figure V-2)

The Nicaragua-Costa Rica Route (Route 8) was discarded from further consideration by the Atlantic-Pacific Interoceanic Canal Study Commission because of its expense in

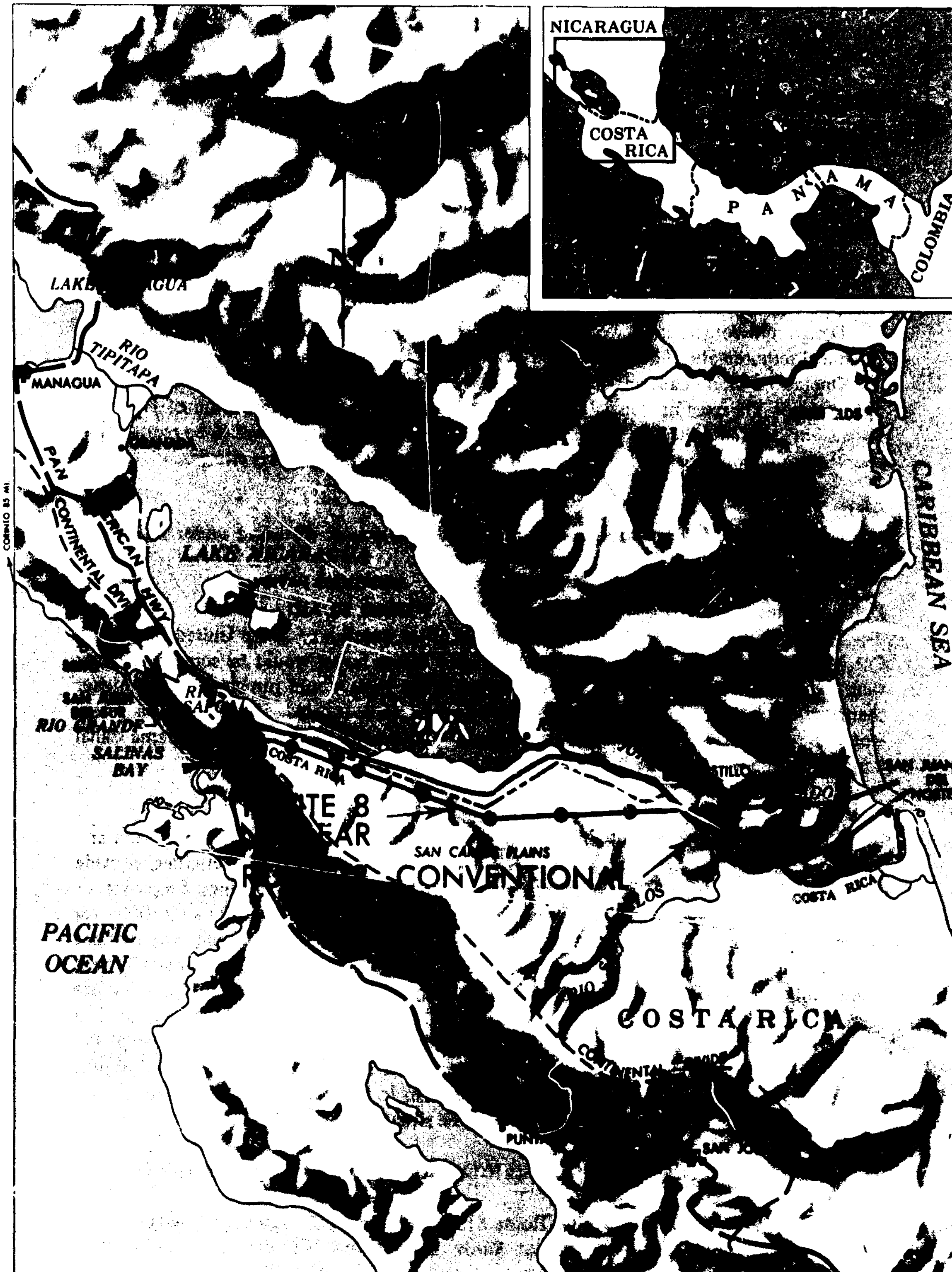


FIGURE V-2

ROUTE 8
NICARAGUA-COSTA RICA BORDER AREA

SCALE IN MILES
10 0 10 20 30

comparison with other canal routes. Both nuclear and conventional construction techniques were examined on a route lying just south of Lake Nicaragua. It was estimated that a conventionally constructed sea-level canal would require a prohibitively high cost ($11 billion). On the other hand, while actual construction cost of a nuclear canal would be much lower ($5 billion), the necessary relocation of 675,000 inhabitants would involve unacceptable social and economic costs.

The Study Group did not find any significant foreign policy advantages that would counterbalance these technical disadvantages.

CHAPTER VI

HEMISPHERIC INTEREST IN A SEA-LEVEL CANAL

ECONOMIC CONSIDERATIONS

Effect of the Canal on Latin American Trade

Latin American countries characteristically rely heavily on the export of basic commodities, and this export trade is almost entirely dependent on ocean shipping.

Latin American trade makes up a relatively small percentage of the canal's total traffic. Of the traffic transiting the canal from the Pacific to the Atlantic in 1968, 3.9% terminated in Latin America and 31.5% originated there. The Latin American contribution in the opposite direction was 19.0% bound for Latin American ports and 17.2% shipped out of them, but most of the latter figure and 27.8% of the entire Atlantic to Pacific trade represents petroleum products being shipped from Venezuela or West Indian refineries.

The principal United States trade with Latin America is not transported through the canal. The canal is an important link for the passage of ore from the west coast of Latin America, and manufactured goods from the east coast of the United States. Some petroleum passes from the Caribbean Sea to the west coast of the United States. Yet only 10% of United States imports from Latin America come through the canal and only 20% of United States exports to the area pass through that route.

Since Latin American trade either in origin or destination accounts for only 5-10% of total canal trade when the Atlantic to Pacific petroleum trade is excluded, the Latin American countries are not major contributors to total canal revenue. The canal, however, is a major determinant of the economies of several Latin American countries. Table VI-1 on the role of the Panama Canal in world ocean trade—1969 demonstrates the high percentage of the trade of various nations of Latin America which utilize the canal.

This overwhelming economic reliance on the canal by Ecuador, El Salvador, Nicaragua, Chile, Peru, Panama, Guatemala and Costa Rica, and to a lesser extent Colombia , Honduras, Mexico, and Venezuela, may result in political effects which far outweigh their contributions to canal revenues. At the present time the canal is taken for granted in most of these countries, but public awareness could grow rapidly if the economic welfare of these countries seemed threatened by changes in the canal operation.

The significant effect of the various proposed canal options on Latin American trade would be the effect of the particular option upon shipping costs. The construction and operating costs of the several canal options vary considerably. To the degree toll rates are affected by construction costs, the exports of these countries would be more or less competitive in world markets in direct relation to the cost of the canal. The various canal options could affect Latin American trade. Due to the relative speed and ease with which ships could utilize a canal, the different canal options would result in varying transit times. To the extent that transit time is reduced, shipping costs would be lowered.

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TABLE VI-1

PANAMA CANAL USERS, FISCAL YEAR 1969[1]

Country	Long Tons of Commercial Cargo Origin	Long Tons of Commercial Cargo Destination	Percent of Country's Total Oceanborne Trade
United States	44,010,410	27,618,123	15.8
(U.S. Intercoastal)	(3,851,326)	(3,851,326)	
Japan	7,396,528	33,558,400	11.7
Canada	7,280,101	2,335,207	7.5
Venezuela	8,528,294	704,973	4.7
Chile	3,325,839	4,063,013	39.6
Peru	4,678,162	1,768,126	39.0
United Kingdom	979,589	3,362,642	2.0
Netherlands West Indies	3,720,671	113,646	4.5
Netherlands	470,062	2,737,548	1.7
Australia	1,668,788	1,367,957	4.1
West Germany	790,825	2,085,378	2.6
Ecuador	969,256	1,215,417	72.4
Philippine Islands	1,534,594	545,703	8.3
New Zealand	1,309,822	702,091	17.6
South Korea	252,799	1,672,353	12.2
Colombia	1,061,716	611,011	22.2
Cuba	1,084,094	479,554	9.8
Panama	1,229,607	331,358	31.5
Canal Zone	17,165	1,436,424	–
Mexico	677,417	758,039	12.8
Belgium	706,125	794,153	1.9
France	334,326	941,959	0.9
Italy	185,766	1,032,002	0.6
Formosa	307,414	923,642	8.9
El Salvador	207,8[illegible]	870,014	68.1
Poland	343,564	75,297	2.9
Trinidad/Tobago	680,661	108,642	2.3
South Vietnam	–	772,063	10.2
Nicaragua	166,801	494,675	55.1
Brazil	387,816	240,668	1.3
Puerto Rico	100,397	514,360	–
Spain/Portugal	108,216	452,971	0.8
Jamaica	427,746	113,646	4.0
China	343,290	192,271	2.5

(Continued on following page)

[1] Countries are ranked in accordance with total of origin and destination cargoes in Fiscal Year 1969. Canal per cent of country's total oceanborne trade is based upon data contained in the United Nations Statistical Yearbook, 1970.

TABLE VI-1 (Cont'd.)

PANAMA CANAL USERS, FISCAL YEAR 1969

Country	Long Tons of Commercial Cargo Origin	Destination	Percent of Country's Total Oceanborne Trade
Costa Rica	276,139	237,150	30.9
Guatemala	74,396	407,349	30.9
Indonesia	66,578	413,416	1.8
Hong Kong	193,990	230,662	3.7
East Germany	355,160	48,179	4.2
French Oceania	130,498	246,157	–
Sweden	164,508	195,267	0.5
British Oceania	319,320	38,007	–
British East Indies	188,277	22,919	–
Netherlands Guiana	268,765	–	–
Honduras	210,642	20,602	13.6
USSR	187,477	32,731	0.2
Thailand	68,656	151,272	1.7
North Korea	57,493	127,350	12.1
Denmark	52,777	128,345	0.6
West Indies Associated States	134,371	40,023	–
Norway	103,574	66,836	0.3
Finland	153,050	–	0.6
Guyana	140,418	–	2.8
Yugoslavia	11,491	128,340	1.1
Argentina	36,886	56,355	0.5
South Africa	–	92,317	0.4
Irish Republic	–	75,831	0.7
Haiti and Dominican Republic	10,004	59,844	1.6
Rumania	62,867	–	0.9
Israel	–	56,452	0.9
Libya	–	40,278	–
Greece	–	32,423	0.2
Lebanon	–	26,380	0.1
Morocco	–	12,995	0.1
Mozambique	–	10,100	0.1
British Honduras	1,636	–	0.8
All Others	2,311,328	3,299,726	
TOTAL	101,391,132	101,391,132	

Contribution to Latin American Economic Integration

One of the first effects of the opening of the Panama Canal in 1914 was to eliminate the trade route around Latin America and as a result decrease the commerce among Latin American countries. The pattern of trade shifted. Even when trade did take place between, for example, Peru and Argentina, it was often trans-shipped through London.

One of the basic assumptions of the Latin American Free Trade Association (LAFTA), as well as of the Andean subregional group, is that there are important economies of scale in the production of many industrial goods. At present many high cost industrial products are produced in Latin America for limited national markets behind import barriers. It is hoped that LAFTA and other international efforts will lead to the replacement of numerous small and inefficient plants by more efficient units scaled to producing for a multi-national market. However, the scope of the market and the event to which the advantages of large scale production can be realized are limited by transport costs among other things. Thus a more efficient canal would contribute toward achieving the goal of Latin American economic integration.

NUCLEAR CONSIDERATIONS

Latin American Nuclear Free Zone

The Treaty for the Prohibition of Nuclear Weapons in Latin America does not prohibit the nuclear excavation of an interoceanic canal by the United States. Article 18 permits the contracting parties to collaborate with third parties for the purpose of carrying out explosions of nuclear devices for peaceful purposes in accordance with specific provisions. It includes requirements that contracting parties must provide certain information to the International Atomic Energy Agency and to the regional control institution for the treaty.

CHAPTER VII

WORLDWIDE ASPECTS OF CONSTRUCTING A SEA-LEVEL CANAL

NUCLEAR EXCAVATION

International Treaty Restrictions

In addition to the requirements of the Latin American Nuclear Free Zone Treaty, two other treaties bear on nuclear excavation: the Treaty Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space and Under Water (Limited Test Ban Treaty) and the Treaty on the Nonproliferation of Nuclear Weapons (Nonproliferation Treaty).

Limited Test Ban Treaty

The Limited Test Ban Treaty, to which the United States and Panama are parties and Colombia is a signatory, presents two distinct problems of relevance to nuclear excavation. The first is the degree to which the treaty may restrict the ability of the Atomic Energy Commission to develop nuclear cratering technology to the point where it can be demonstrated to be feasible and an authoritative assessment can be made of its safety and cost. The second is that a treaty modification is needed to permit the actual nuclear excavation of a canal in Panama or Colombia.

The treaty prohibits "any nuclear weapon test explosion, or any other nuclear explosion in the atmosphere, in outer space or under water." The treaty also prohibits "in any other environment," meaning underground, "any nuclear weapon test explosion or any other nuclear explosion...if such explosion causes radioactive debris to be present outside the territorial limits of the State under whose jurisdiction or control such explosion is conducted." Explosions for peaceful purposes are subject to the same restrictions as nuclear weapons tests; i.e., they are permissible only if: (1) carried out underground, and (2) they do not cause radioactive debris to be present beyond territorial limits. This second criterion is technically imprecise and therefore gives rise to questions of interpretation.

Even if nuclear excavation experimentation is successfully carried to completion and if considerations seem to recommend nuclear excavation, given the short distance from territorial borders of the most probable construction sites, construction could not be done under present interpretation of the Limited Test Ban Treaty limitations. The negotiators of the treaty were fully aware, however, that the peaceful use of nuclear explosives might prove feasible and desirable in subsequent years. They deliberately made it possible to amend the treaty for this purpose by a simple majority (rather than by a two-thirds majority) of the parties, provided that the three principal signatories agreed.

The Non-Proliferation Treaty

The Non-Proliferation Treaty would not prohibit the nuclear excavation of an interoceanic canal by the United States. While the treaty prohibits non-nuclear weapon states from having their own nuclear explosive devices, Article V provides that non-nuclear nations shall have the benefits of nuclear excavation technology at minimum cost if and when such excavation proves feasible. The first version of this article was simply a paragraph

in the Preamble, but in light of the considerable interest expressed by non-nuclear weapon states it was included as an operative article of the treaty.

One other aspect of the Non-Proliferation Treaty is worthy of comment. Throughout the discussions of the treaty there were strong demands by the non-nuclear weapon states for further steps toward disarmament, and this is reflected in Article VI of the treaty as well as in the Preamble. These provisions presage considerable pressure to continue negotiations toward a Comprehensive Test Ban Treaty. While it is reasonable to expect that a Comprehensive Test Ban Treaty would provide for continuing development and utilization of peaceful nuclear explosions, the realization of such a treaty before or during the construction of a canal might impose additional restrictions or procedural requirements on the use of nuclear explosives for the construction of a transisthmian sea-level canal.

The peaceful application of nuclear explosives is still in a relatively experimental stage. Its technical and economic feasibility has not been fully demonstrated and its collateral effects are not completely known. If testing is permitted to continue, and if the technical advantages and safety of nuclear excavation techniques are established beyond a reasonable doubt, relief from the problem of treaty restrictions on the use of nuclear excavation probably can be obtained more easily.

The Effect of World Opinion

Reaction among the nations of the world to the employment of nuclear explosives for building a canal would depend largely upon what had transpired in the peaceful use of atomic energy, and on how convincingly and in what manner the United States and other interested powers had presented their case. If progress had continued and news of that progress had been disseminated to the leaders and peoples of other nations, there probably would be little difficulty.

The discussion of foreign policy aspects of the use of nuclear explosives in construction of a sea-level canal has focused on problem areas connected to such a project. This should not, however, over-shadow the tremendous prestige and respect that would accrue to the United States for successful completion of an internationally used utility through the peaceful application of atomic energy.

In summary, it appears that if it can be proved that nuclear excavation is technically feasible and the health and safety measures would not involve too much disruption to peoples' lives, and if measures were taken to offset economic disadvantages incurred by Panamanians, the political and legal problems involved in the project could be overcome and the feat would redound to the credit of the United States. The real question is the technical feasibility of the project.

ECONOMIC CONSIDERATIONS

Effect of Toll Structures on World Trade

Because of the cost of amortizing any investment in a sea-level canal and of providing a share in the revenues to the Republic of Panama, it is assumed that any change in toll

structures would be upward rather than downward. The effects of an increase in toll rates would be both on the volume of traffic and on the commodities carried.

Profit margins in the shipping industry are such that changes in operating costs generally are shifted to the product being carried. The volume of shipping through the canal can be expected to change with increasing tolls, therefore, either when alternatively less costly routes or other transportation modes are available or when the shift of cost to the commodity being carried becomes so great as to reduce the quantity being shipped. Any disruptions which do take place will have foreign policy implications in so far as they affect the shipping of other nations, the suppliers of goods in international commerce, and the end-users of these goods.

Studies conducted by the Stanford Research Institute and Arthur D. Little, Inc. indicate that, while small changes in tolls would not affect the volume of shipping, diversion of shipping begins as the increases range above 25%. A more recent study, conducted by Arthur Andersen and Company in connection with the Commission's Study of Interoceanic and Intercoastal Shipping, concludes that selective increases averaging 50% over present tolls can be applied without markedly affecting traffic growth. The extent of the disruption depends on whether the toll increases are general or selective and on the magnitude of the increases. Any increase in tolls resulting in a substantial reduction of shipping could produce friction between the United States and the two groups of nations under whose flags most transits of the canal take place. These groups may be categorized as major trading partners of the United States and less developed nations. Any major changes in toll structures would have to be considered not only in the light of their effect on canal revenues, but also in terms of special foreign policy relationships between the United States and these nations.

Many commodities, particularly petroleum, ores, metal and coal which are the highest tonnage items transiting the canal, are so highly competitive that relatively small changes in costs per ton can cause shifts to alternative sources of supply. These bulk items are frequently very important sources of foreign exchange earnings for developing nations and since sailing around Cape Horn is more expensive for bulk carriers, toll rates which effectively raise the price to these suppliers can cause serious economic dislocations. Any analysis of the impact of tolls on the volume of tonnage being shipped must, therefore, be disaggregated to see its effects on shifting sources of supply for various commodities. These shifts must be considered in the light of United States relations with the suppliers affected.

The United States might also find itself involved in foreign policy issues with end-users of products transiting the canal under various circumstances resulting from higher toll rates. For example, a major shift in the rate structure could be translated into generally higher world prices for commodities transiting the canal with resulting world-wide dissatisfaction. This dissatisfaction could be particularly pronounced in the case of poorer nations dependent on food, grains, and other agricultural commodities which are significant items in canal traffic. Also, for several of the Central American countries and Colombia, the canal is an important link between their coastal markets; consequently, increased shipping costs would have a direct and extensive effect on the domestic economy. Once again, any measurement of the effects of a change in the toll structure must be disaggregated, this time to measure its effects on United States relations with end-users of products which are transported through the canal.

Effect of a Sea-Level Canal on World Trade

The foreign policy considerations mentioned above in relation to toll structure also apply to the discussion of expanding the canal. Both tolls and capacity impose limits on traffic. The Shipping Report to the Study Commission demonstrates that the existing canal could be reaching its full capacity sometime during the period 1989-2000; as this date approaches, complications for ships transiting the canal will increase. As of 1970, there were about 1300 ships afloat, under construction or on order which are too large to pass through the canal under any circumstances because of excessive beam width. An additional 1750 such ships cannot pass through the locks fully laden at all times because of draft limitations.

These limitations on quantity and size can complicate world trade by making shipping more costly and difficult, by causing economic dislocations for suppliers, and by restricting supplies to the world's consumers. They thus could tend to retard the rapid expansion of world trade. In so far as a sea-level canal would mitigate these complications and also reduce transit time, it would supply foreign policy benefits which are not so readily apparent when simply measuring the elasticity of canal traffic to changes in the toll structure.

The benefits which do accrue to the United States by removing these potential barriers to world trade are of considerable significance in evaluating the overall desirability of a sea-level canal.

The reduction of barriers to trade lowers costs and increases efficiency at home for, like technological progress, trade widens the range of available ways of transforming labor and other resources into desired goods and services. Technological progress and geographic specialization both make this transformation more efficient. The ready availability of items in world trade reduces artificial incentives for the flow of American capital abroad. It also tends to reduce over-reliance on regional economic groupings and lessens the discrimination our exports face from such groupings. All countries benefit from the specialization, the growth and the exchange of technology, and the spur to productivity that competition in the world market provides.

Seventy percent of the goods transiting the canal originate or terminate in United States ports. The canal is, therefore, in a very real sense our window on the world. We have a definite foreign policy interest in seeing that the window remains fully open to the world of the 21st century.

CHAPTER VIII

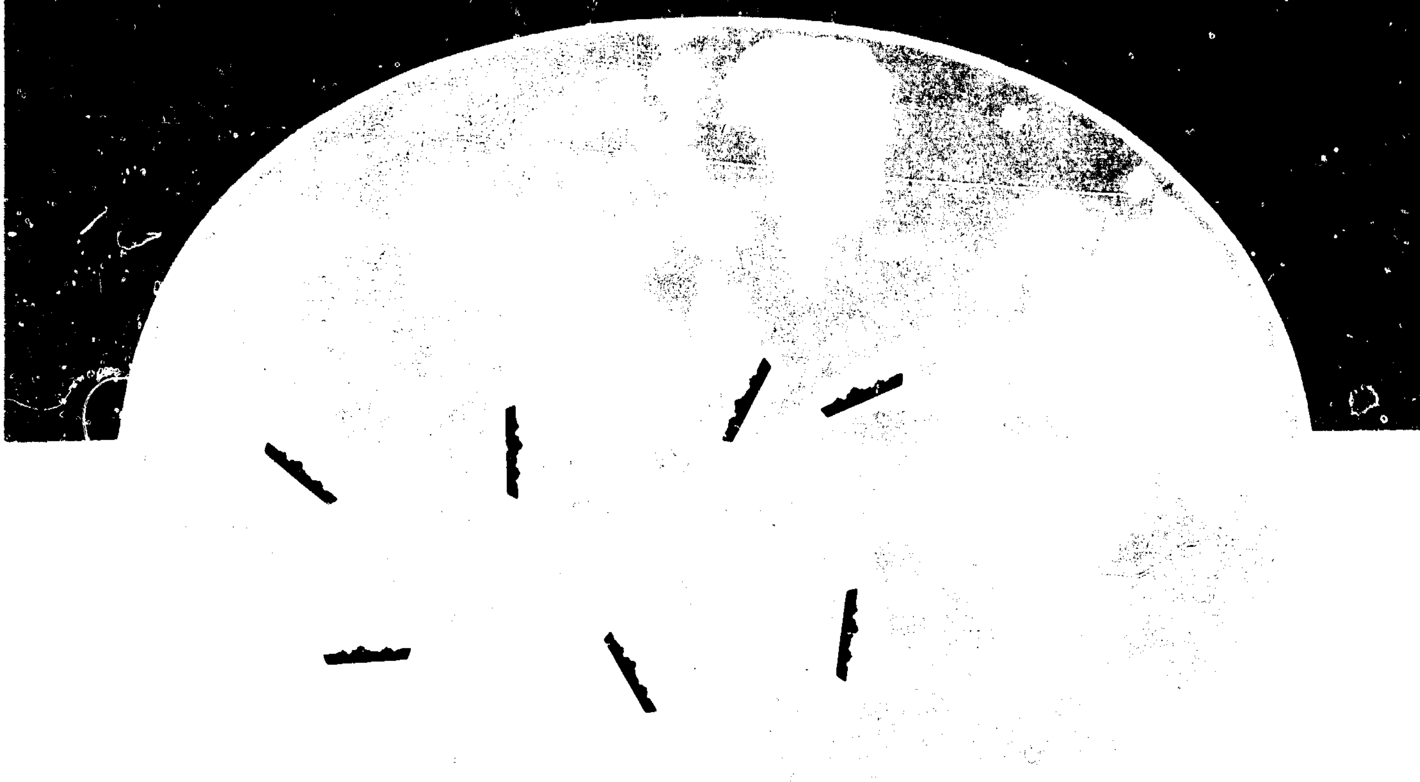
AN ATLANTIC-PACIFIC SEA-LEVEL CANAL: AN INTERNATIONAL PUBLIC UTILITY

There has long been discussion concerning the possibility of arranging some form of multinational participation in the operation of an isthmian canal. The 1967 draft treaties contained provisions for multinational participation in the financing, ownership and operation of a sea-level canal, but the exact terms of an arrangement were left open for future agreement.

United States interest in possible multinational participation stems from political and financial considerations. While United States interests might be served by some form of multinational participation in the future, the foreign policy benefits at present do not appear great. We would hope to reduce the burden on the United States taxpayer somewhat by obtaining international financial support for new canal investment. There is little doubt, however, that the United States would provide the major share of the investment.

Panama has historically resisted multinational participation. The inducements for multinational participation are not great to major user nations, who appear to believe that the operation of an isthmian canal is primarily a United States responsibility.

THE ATLANTIC-PACIFIC INTEROCEANIC CANAL STUDY COMMISSION



Annex II
Study of National Defense Aspects

ANNEX II

FINAL REPORT
(ABRIDGED)

ON

THE EFFECT OF CONSTRUCTION OF AN
ATLANTIC-PACIFIC INTEROCEANIC SEA-LEVEL CANAL
ON THE NATIONAL DEFENSE OF THE UNITED STATES

BY THE

NATIONAL DEFENSE STUDY GROUP

ATLANTIC-PACIFIC INTEROCEANIC CANAL STUDY COMMISSION

WASHINGTON, D.C.

JUNE 1970

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INTRODUCTION

In October 1965 the Atlantic-Pacific Interoceanic Canal Study Commission requested the Secretary of Defense to undertake a study of the national defense aspects of a sea-level canal. At the direction of the Secretary of Defense, the study was initiated under the auspices of the Secretary of the Army, who appointed the Deputy Under Secretary of the Army (International Affairs) as study group chairman.

The purpose of the National Defense Study was described by the Commission as follows:

> "To determine the effect of the construction of an Atlantic-Pacific sea-level interoceanic canal on the national defense of the United States and to compare the alternate routes and methods of construction from the standpoint of national defense."

The study group was organized from members assigned to the concerned offices within the Department of Defense, and from the Department of State, Department of Transportation, and the Atomic Energy Commission. The study has been developed, refined and updated through five annual drafts. The final report represents the sixth comprehensive review. This document is the abridged and unclassified version of the final report.

The study is organized into five chapters. Chapter I presents the conclusions derived from the analysis of the defense aspects. Chapter II analyzes the strategic mobility and logistic support considerations of a sea-level canal. Chapter III discusses the vulnerability and defense requirements of a canal. The regional security aspects of a sea-level canal and its associated defense bases are considered in Chapter IV. In the final chapter the national defense considerations of the method of construction are analyzed.

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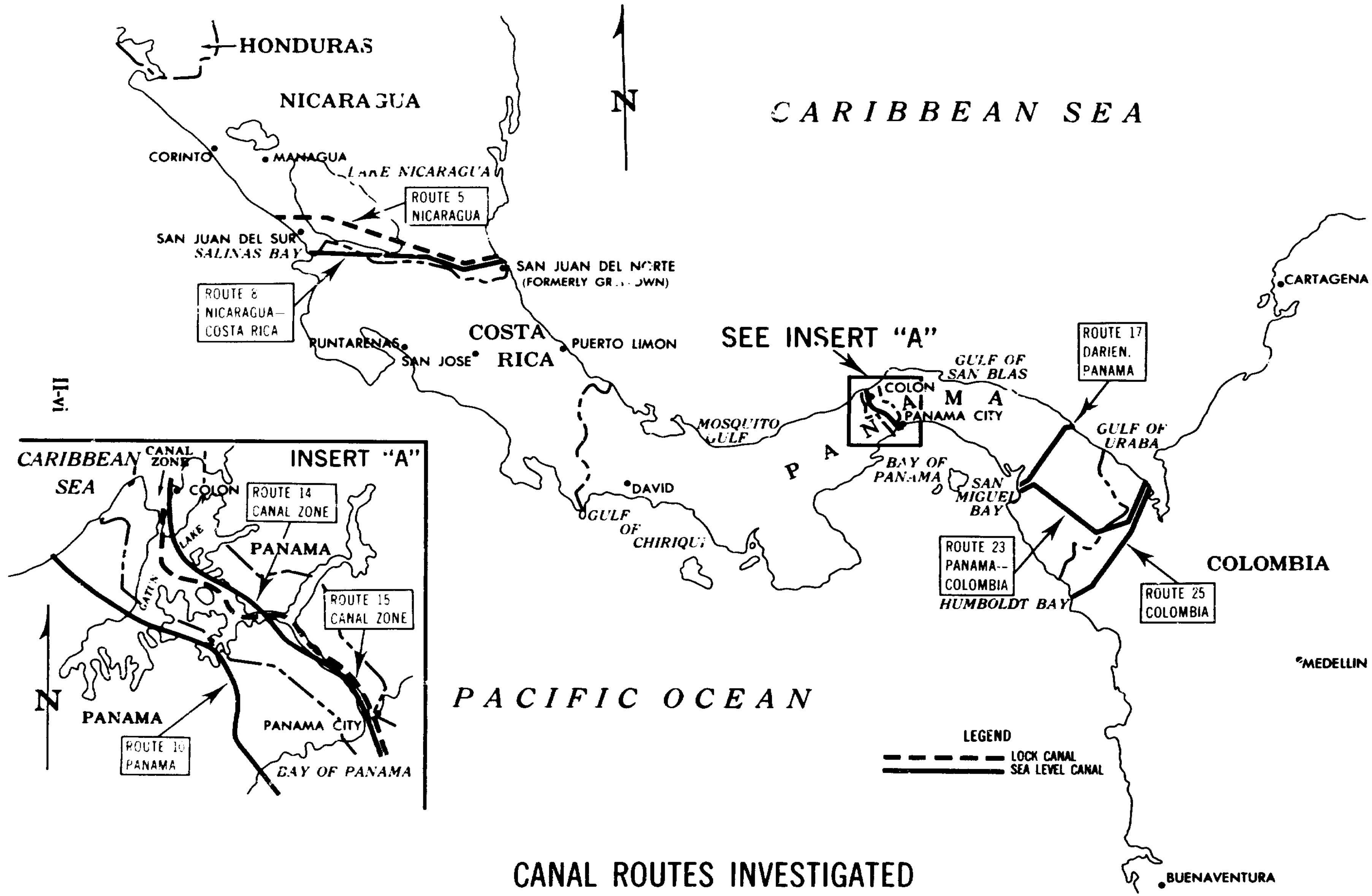

CANAL ROUTES INVESTIGATED

CHAPTER I

CONCLUSIONS

The National Defense Study Group supports the following conclusions with regard to the national defense aspects of a sea-level canal:

1. A sea-level canal would represent a major defense asset for the United States. It would economize defense efforts by meeting:
   a. The continuing requirement to shift naval power to meet changing threats and situations, a requirement which could be pressing in the future due to existing United States commitments and projected force level constraints.
   b. The continuing requirement to move logistic support by surface shipping to overseas areas in:
      (1) Peacetime
      (2) Stability operations
      (3) Limited war
      (4) General war. In this category of warfare, the canal would facilitate recovery of the United States from a general war attack.
2. A sea-level canal would meet the requirements of the increased size of both naval and merchant ships.
3. A sea-level canal would be far less vulnerable than either the present canal or any of the modernized versions of the third lock canal. Damage to any sea-level canal sufficient to necessitate re-excavation would require an accurately delivered multi-megaton attack. A totally nuclear excavated canal, by virtue of its greater depth and cross sectional area, would be less vulnerable to blockage than a conventionally excavated canal.
4. A sea-level canal would better provide for both peak period traffic demands and long-term (annual) traffic requirements. The greater peak period capacity of a sea-level canal would significantly ease the time phasing requirement necessary to avoid a lucrative target bottleneck. The greater annual capacity would meet the demands of military shipping while minimizing commercial shipping travel time. This would not be possible if the present lock canal were operating at capacity or near capacity as can be expected by the end of the century.
5. Considering the foregoing and the location of Routes 8, 10, 14, 17, and 25, a sea-level canal at any one of the routes would be adequate, whether constructed by conventional or nuclear means, for military transit requirements and would represent a significant improvement from a defense standpoint over the present lock canal and over a third lock-type modernization.
6. Due to its reduced vulnerability and greater capacity, a sea-level canal constructed wholly by nuclear means is preferable from a defense standpoint to a conventionally excavated canal or one that is constructed by a combination of nuclear and conventional

excavation. For this reason, if there is no national decision to construct in the near future, research and development efforts should continue in order to develop a nuclear excavation capability for future canal construction.

7. If only conventional excavation methods can be employed, Route 10 possesses a significant advantage over Route 14 primarily in that construction of Route 10 would leave the present lock canal as a backup facility after construction and would not hazard the present canal during construction.

8. A transisthmian canal, either lock or sea-level, is of major and continuing importance to the national defense of the United States.

9. By providing for Canal Defense our bases would render a major contribution to regional security of the Americas.

10. Neither the conventional nor the nuclear construction effort required to build a sea-level canal would tax the construction resources of the United States.

CHAPTER II

STRATEGIC MOBILITY AND LOGISTIC SUPPORT

INTRODUCTION

This chapter examines the contribution of the Panama Canal to the mobility of United States naval forces and to the ocean-borne logistic support of all types of overseas military operations and estimates the effect which construction of a sea-level canal at various locations would have on these aspects of the national defense. It reviews the past role of the Panama Canal in naval deployments and logistic support, the limitations which the present canal imposes and the role of the Canal in relation to current strategic concepts; and it projects the use which could be made of a sea-level canal in implementing United States strategy as it may evolve to meet world conditions in the future.

Study of the past, present and future role of an Atlantic-Pacific interoceanic canal indicates that it shortens significantly the time to deploy forces at the beginning of a conflict in almost any part of the world, and that as the conflict progresses the cumulative saving of time results in bringing into action greater military force for the same supporting resources. Put another way, such a canal economizes the effort needed to apply the required military power.

Since the advent of the larger aircraft carriers, a major element of United States naval power has been unable to transit the Panama Canal. While the decision to build these ships removed a design constraint from our naval architects which led to more effective modern weapons systems, it had the adverse effect of increasing the time of transit of these ships between the Atlantic and Pacific fleets. Construction of a sea-level canal would result in economies and would permit greater flexibility in the deployment of our carrier strike forces, a major factor in the effective employment of seapower. While the uncertainties inherent in the necessity to navigate a restricted passage would require planning and preparations for the contingency that use of the canal might be denied, at least temporarily, a sea-level canal would be considerably less vulnerable to such closure than would the present lock canal. Although it is not possible to quantify in concrete terms the advantage which a sea-level canal would afford over the present canal, this chapter presents the best estimate of the net advantage that can be made with data currently available.

CONTRIBUTIONS OF PANAMA CANAL TO NAVAL MOBILITY AND LOGISTIC SUPPORT

The Panama Canal has provided a steadily increasing contribution to our national strength and security since its opening in 1914. Through the years the number of ships

annually transiting the Panama Canal has increased from 1,100 to more than 15,500. During World War II some 5,300 warships and 8,500 other ships carrying troops and cargo for military use passed through the canal. Again, during the Korean War, the canal facilitated the rapid movement of logistic support for military operations. It has been estimated that during FY 1953, 22 percent of Army tonnage directed for Korea was shipped from East or Gulf Coast ports through the canal.

The logistic support required by current military operations in Southeast Asia has also increased military use of the canal. Between 1964-1968 there has been a 640 percent increase in dry cargo tonnage and a 430 percent increase in POL* tonnage moved into the Pacific Ocean through the Panama Canal by the Military Sea Transportation Service which provides the logistical surface shipping support for United States military operations overseas. During FY 1968 approximately 28 percent of the POL sent to South Vietnam, Thailand, Philippines, Guam, Okinawa and Japan transited the Panama Canal.

Experience since 1940 shows that logistic requirements for military operations have steadily increased and can be expected to do so further in the future. The complicated machines of modern war have increased the need for logistic support of all kinds. In this regard POL and ammunition are particularly important. Consumption per man per day has markedly increased. The bulk characteristics of these two classes of supply suit them particularly for ocean shipment. Another factor which dictates an expanded need for ocean transport is the increasing quantity of motorized ground and airmobile equipment of larger dimensions.

The importance of a transisthmian canal can be demonstrated by hypothesizing the following case: move 80,000 personnel and 3,000,000 measurement tons of supplies to the Pacific from Atlantic and Gulf Coast ports through the Panama Canal. Using the factors of a troop transport capacity of 3200 personnel and a cargo ship capacity of 7200 measurement tons, the number of ships required for total lift at one time approaches 450. Closure of the Panama Canal would approximately double the requirements for ships to support operations in the Pacific at the same level of support. In general, the most sensitive transport capability resource is ocean shipping and in most cases, because of the large tonnage required, ocean shipping will account for about 90 percent of total deliveries.

Since its opening the canal has been a prime consideration in the planning for and accomplishment of the safe and timely movement of naval units between the Atlantic and Pacific Oceans. A saving in distance of approximately 8,000 miles is realized by canal transit, versus rounding Cape Horn, in the deployment of ships from one coast to the other. A time saving of up to 30 days can accrue for slower ships and at least 15 days for fast ships (20 knots). The capability to shift rapidly naval power between the Atlantic and Pacific Oceans presents a significant advantage to the country controlling the Isthmian passage.

Our world-wide contingency planning would require an increase in the active naval forces if we were denied the flexibility resulting from our ability to move naval vessels quickly from the Atlantic to the Pacific. If the active naval force level cannot be increased, the alternatives are to accept increased reaction time which could result in increased losses or at least in accepting greater risk of increased losses.

The savings in steaming time and distance resulting from use of the canal during World War I and II by both naval and logistic support forces produced the important end benefit

*Petroleum, oil, and lubricants

of reduced exposure to the enemy submarine threat. A basic concept of shipping protection in that ships could be at sea for the shortest period of time necessary to accomplish their mission. By eliminating the necessity of the long voyage around Cape Horn, the U-Boat operating area along the northeast coast of South America was bypassed and the necessity for ASW operations in the area was removed. While it is impossible to forecast future naval operations precisely, it appears reasonable to assume that an advantage of this nature also would occur in future military operations in which the enemy has a significant naval capability.

A concomitant commercial and logistic advantage of a sea-level transisthmian canal is that it would allow shipping (that too large to transit the lock canal) to avoid the natural hazards of the Cape Horn and Strait of Magellan area. It should be noted, however, that large vessels would probably use the Cape Horn route in spite of its hazards if it represented a clear economic advantage over use of the sea-level canal. The principal dangers to navigation are narrow channels, poor weather conditions, and tidal currents in the Strait of Magellan and icebergs and frequent gales in the Cape Horn area.

Due to these hazards the continuous large-scale use of Cape Horn and the Strait of Magellan would result in the attrition of men and shipping involved. In this regard a transisthmian canal would husband our naval and maritime resources.

ADEQUACY OF PRESENT CANAL

Though the present Canal makes a major contribution to the strategic mobility of the U.S. Navy, it does not provide an unrestricted passage for all naval ships. The present Canal is incapable of providing transit for the Navy's fifteen attack aircraft carriers (CVA) and four antisubmarine aircraft carriers (CVS). Thus, the flexibility of the Navy's nuclear striking power and antisubmarine aircraft carrier capability is restricted by the limitations of the existing lock canal. In this respect the Canal is obsolescent.

An example of the effect which the inadequacy of the present Canal already has had on operations in Southeast Asia was the interocean movement of the aircraft carriers ENTERPRISE, INDEPENDENCE and BOXER, and the communications configured escort carrier ANNAPOLIS. The saving in distance on these deployments from the East Coast to the operating area of Vietnam via the Panama Canal would have been as much as 5,000 miles per ship. A saving in time of as much as 11 days per ship could have been realized depending on the speed of advance.

In addition to the U.S. Navy aircraft carriers which are too large to make the transit, there are about 1,300 ships afloat, under construction, or on order which cannot enter the Panama Canal locks. There are approximately 1,750 more ships in these categories that cannot pass through the Canal fully laden at all times because of draft limitations due to seasonal low water level.

When considering the limitations of the Panama Canal it should be recognized that the Suez Canal also has a ship size limitation, particularly with regard to channel depth. Today, carriers of the MIDWAY, ENTERPRISE, AMERICA, KITTY HAWK and FORRESTAL class could not transit the Suez Canal if it were reopened. This means that the Suez Canal will no longer provide an alternative routing for this type of naval ship. Loss of the Panama route as well as the Suez route would severely restrict the flexibility of our naval resources.

For example, a ship which required 25 days to go from New York to Tokyo through the Panama Canal would require 34 days via the Suez Canal. If required to go around the Cape of Good Hope, the sailing time would be 38 days.

Any consideration of adequacy of the existing canal should include its vulnerability. The locks, dams, power systems, and the depth and width of the Gaillard Cut make the present canal a vulnerable target. In certain situations the canal could be closed for two years. A sea-level canal would be far less vulnerable. Considering the more likely methods of attacks, 5 days to two weeks is a reasonable estimate of closure time for a conventionally excavated sea-level canal. Closure of a nuclear excavated canal would be extremely difficult short of seizure.

An alternative to a sea-level canal as the answer to the growing obsolescence of the Panama Canal is its improvement and modernization. In this regard the interest of the Engineering Agent of the Canal Commission has been centered on a lock canal option utilizing a third set of locks capable of carrying 150,000 DWT ships. The total capacity of such an augmented canal would be approximately 35,000 transits per year. Principal features of this plan include very large additional locks, deepening and widening of the canal and the pumping of sea water into Gatun Lake or the recirculation of fresh water to meet the increased water requirements. The major defense disadvantages of this type solution are the vulnerability to sabotage and blocking and the inability of this canal to transit the Navy's large aircraft carriers.

ADVANTAGES OF SEA-LEVEL CANAL IN FUTURE APPLICATION OF MILITARY POWER

Current strategic concepts are inherently interrelated to the varying levels or intensities of military conflict. To a significant degree they reflect the resources the United States is willing to expend to meet a particular threat. A sea-level canal would make a contribution across the military spectrum, although the importance of this contribution varies greatly between types of conflicts and between specific conflicts of the same general type.

General war is usually considered to consist of two phases. The first involves the period of the nuclear exchange and the second is the period which follows the exchange and in which the war is brought to conclusion.

Assuming the first phase lasts a matter of hours or at most days, the canal probably would have no role to play. Depending on the length of strategic warning, however, the canal could play a major role in the prepositioning of both combat naval forces and land forces. A sea-level canal would have the advantages of the reduced time and distance factors present in today's Canal as well as the additional advantages of an increased vessel size capacity and of reduced time of transit. Transit time in this type emergency would be very nearly a function of ship speed, rather than today's lock manipulation time. While it may be argued with some considerable merit that the degree of strategic warning postulated above is unlikely, the advantage which this additional option provides should not be disregarded.

Assuming a general war, a sea-level canal could well play a major role in the survival of the United States as a major world power during the second period. During this time of wide-spread destruction and chaotic social and economic conditions the rapidity of relief

may well be as important as the relief itself. Succor will have to come from the less damaged areas of the world. An operational canal would facilitate the flow of these supplies to the appropriate areas of the United States.

Moreover, the canal would fill to some extent the gap created by the disruption of cross-country land transportation. The proper distribution of surviving resources will be a very difficult problem at best. Closure of the canal would make it more so.

The ability to use the canal for rapid deployment of the residual forces of the United States would be of great importance to the successful continued prosecution of the war.

Limited war and stability operations are characterized by conscious restraint with regard to one or more of its aspects, e.g., objectives, forces, weapons or locale. However, it may involve very large forces between major powers engaged in a considerable area of operations. Because of the magnitude of general war destruction, limited wars and other less formalized military operations have become the most prevalent and probable type of conflict. The increasing destructive power of modern weapons appears to assure that this trend will continue in the future. Certainly, the history of conflict since World War II makes it clear that wars or engagements of limited scope are the more likely. It is also clear that the ability to react rapidly in situations requiring the use of armed force may make the difference between a crisis which has been calmed and one which gets out of control.

It is important for the United States to preserve the capability to respond quickly with the proper level of military power in response to commitments abroad. Fundamental to this concept is the ability to employ our superiority on the seas to maximum advantage. In planning for the future, the continued use of the seas will remain important to the ability of the United States to apply military power with speed and discrimination wherever required in the national interest.

As national economic restraints make themselves felt on naval force levels, the sea-level canal's capability to provide the U.S. with "interior lines" between the Atlantic and Pacific becomes of even greater importance. The ability to quickly move major vessels and shipping from one ocean to the other is obviously a tremendous advantage. A sea-level canal would not only permit the faster inter-theater transfer of carrier forces, which the present canal cannot accommodate, but would provide a greater capacity for handling shipping of all types in an atmosphere of reduced vulnerability to damage. Because of the emergence of the Soviet Union as a world power with a major submarine fleet, the United States Navy could conceivably be confronted with a situation in which the interior lines of deployment through a relatively invulnerable sea-level canal assume greater importance than has been true since the opening of the Panama Canal.

In World War II (1941-1945), United States Government vessels made 20,276 transits, and 24 million tons of military supplies passed through the Canal. During the Korean War (1951-1954), United States Government vessels made 3331 transits, and 12 million tons of supplies went through. The Canal played an important role in the deployment of naval vessels during the Cuban crisis in 1962. In dealing with any possible future conflicts strategic mobility on the seas will continue to be of great importance. The capability of naval forces to respond in a timely manner with appropriate power and with the ability to move troops and supplies with safety and assurance across the oceans to the scene of conflict is essential. In accomplishing these tasks the availability of a sea-level transisthmian canal would provide a significant strategic advantage. Current operations in Southeast Asia bear this out.

Although Vietnam is a Pacific nation, major logistic support for the war flows from the East and Gulf Coasts of the United States. Since the closure of the Suez Canal in June 1967, this support has utilized the Panama Canal almost in toto. While shipping times are longer from the East Coast, they are not prohibitively so, particularly in the role of long-term logistic support. Average sailing time to Vietnam from East Coast ports is 37 days, from West Coast ports 25 days.

Total cargo in FY 1967 (1968) shipped through the Canal in support of United States efforts in Southeast Asia was approximately 5.190(7.2) million long tons or about 5.6 (6.8) percent of total Canal cargo tonnage transited. During FY 1968, of a total of 11,947,000 measurement tons of dry cargo shipped from CONUS for the military services by MSTS to South Vietnam, Thailand, Philippines and Guam, 3,942,066 measurement tons were shipped via the Panama Canal (approximately 33%). As regards POL, a total of 14,118,588 long tons was shipped for use in support of operations in Southeast Asia, 4,104,970 long tons were shipped via the Panama Canal (approximately 29%).

The role of the Panama Canal in support of the war in Vietnam shows that it is not only of major logistic and strategic importance in the lower intensity conflicts, but also cost effective in the performance of that role.

FURTHER CONSIDERATIONS

Having discussed the importance of a transisthmian canal to past and present military operations, the advantages of a sea-level canal over the present lock canal require further consideration. These advantages fall into the following general categories:

(1) vulnerability or survivability (See Chapter III)
(2) peak period transit capacity
(3) long-term transit capacity, and
(4) ship size capacity

Peak period capacity of the present canal may be addressed in terms of its daily lockage limitations. The rated daily capacity is estimated at 65 lockages or about 71 ship transits. These figures are the result of many factors such as operator efficiency, condition of equipment, and time required for lock manipulations–filling or emptying a lock, opening and closing gates. These capacity rates cannot be sustained on an annual basis due to present limitation on the lockage water supply. They could be sustained for a rather extended period, however, provided the Gatun and Madden Lakes were at a sufficient level at the time in question.

Based on the currently estimated transit speed of 7 knots and single lane traffic, the daily capacity of a sea-level canal in Panama would be between 90 and 180 transits. Such a ceiling means, in effect, that the peak transit capacity would not be a major limiting factor for future military use. With the lock canal it could be. The requirement to time phase shipping through the canal in order to avoid a target bottleneck would be significantly eased.

Annual transit capacity today is limited by the availability of water for lockage. Basically the present water supply limits the number of lockages to approximately 18,000 transits annually if an acceptable water level is maintained in Gatun Lake. Annual transit

capacity has been estimated to be approximately 27,000 provided additional improvements costing $92 million are made. The annual figure would more than provide for any reasonably foreseeable military shipping requirements. The range of future shipping estimates indicates that a capacity of 27,000 transits would be reached by normal commercial traffic between 1989 and 2000. The capacity range of the sea-level canal options under principal consideration is up to 80,000 ocean-going transits per year.

Ship size capacity. A sea-level canal would not have the ship size restriction of the present lock canal. The present restriction derives from the dimensions of the locks (110' wide and 41' deep by 1,000' long). The dimensions currently being considered for a conventionally excavated sea-level canal are 550' x 75' at the edges with an 85' deep centerline. A nuclear excavated canal would be 1,000' wide with a minimum depth greater than 100', which would run to 250' deep at canal center.

The United States naval combat ships that cannot utilize the Panama Canal have already been enumerated. During the period 1953-1969 there have been 36 interoceanic transfers of such vessels; however, 19 of these transfers have occurred since the Gulf of Tonkin incident. Navy planning has tended to minimize the interocean transfer of large units due to the transit time and cost involved. If a sea-level canal had been available a far greater degree of deployment flexibility would have been afforded. The requirement for timely redeployment of even our largest fleet units would become increasingly important in the event of reduced force levels.

Until World War II, the size of U.S. Navy ships was limited by the size of the locks of the Panama Canal. Even today the size of the canal locks is still a major consideration in naval design. In those cases there is little question that this artificial constraint has had an adverse effect by not permitting naval architects to maximize operational capability in all cases. In those cases where the trade-off is not considered excessive this is still the case, e.g., the proposed Fast Deployment Logistic (FDL) Ship has been designed to allow transit of the Canal.

The construction trend in many other naval vessels, however, is toward larger ships which cannot be accommodated by the Canal. The specifications for current nuclear powered attack aircraft carriers (CVA) include a beam width of 257 feet at flight deck level, a length of 1,040 feet, and a draft of 37 feet. U.S. Navy combination oiler and ammunition ships now in service, and others under construction, have beam widths of over 100 feet, lengths over 700 feet and drafts greater than 37 feet.

It is clear that if the United States is to remain predominant on the high seas, the U.S. Navy must continue to take full advantage of future improvements in the areas of ship design and propulsion. An important corollary to a naval modernization program is a sea-level canal which will afford the naval warships of the future expeditious passage between the Atlantic and the Pacific Oceans and at the same time allow naval architects and planners to be constrained by the more liberal restrictions of a sea-level canal.

In view of the strategic significance of future operations at sea, the increasing quantity of logistic support required to sustain military operations, the trend to ships of larger dimensions, and the projected increase in the number of ships requiring passage between the Atlantic and Pacific Oceans, it becomes evident that a sea-level canal would constitute a major asset for the defense of the United States.

COMPARATIVE EVALUATION OF ALTERNATE PROPOSED CANALS FROM STANDPOINT OF STRATEGIC MOBILITY AND LOGISTIC SUPPORT

The ultimate decision on the particular selection of a site for the sea-level canal is not a consideration of paramount importance from the standpoint of strategic mobility and logistic support. The various routes under consideration for a sea-level canal connecting the Atlantic and Pacific Oceans are in such relatively close proximity to one another that the sailing time between them is negligible when considering the overall time to transfer shipping via a canal as opposed to rounding Cape Horn. The most significant consideration from the viewpoint of national defense is that the canal be sea level and thereby eliminate or minimize the inherent disadvantage of a lock canal, such as its vulnerability and limited capacity to handle shipping due to the limitations which the locks place on ship dimension and the time involved in lock operation.

While any of the canal sites under consideration would be adequate from the standpoint of naval mobility and logistic support, a wholly nuclear excavated canal at Route 17 would have advantages over the other routes because of its reduced vulnerability and greater capacity. The overriding consideration, however, is that the canal to be constructed be a sea-level waterway.

CHAPTER III

VULNERABILITY AND DEFENSE REQUIREMENTS

A detailed analysis of the broad spectrum of threats that a sea-level canal would face indicates that the most probable of the threats are sabotage, clandestine mining of the waterway, or the attack of shipping in the canal by low-performance aircraft or readily transportable weapons. The more traditional forms of attack–blockade, naval or aerial bombardment, or ultimately attack by missile-delivered nuclear weapons–are unlikely. These would probably be either part of or evoke a general war situation, confronting the perpetrator with the total military strength of the United States. In addition, such attacks could fail to inflict sufficient damage to prevent the use of the sea-level canal.

The relative invulnerability of a sea-level canal to most types of attack stands in sharp contrast to the vulnerability of the present canal, whether or not it has been modernized. The fact that the present lock canal could be closed by the use of relatively unsophisticated weapons is particularly significant in view of the forecasts which anticipate that insurgency and subversion will probably persist in Latin America to the end of the century. Interruption for extended periods to canal service, which could be achieved with relative ease, would not only seriously hamper the logistical support of military operations in time of war but also adversely impact on international trade in time of peace.

The detailed comparison of the vulnerability of the various canals considered indicates that there is a very significant lessening of the vulnerability of a sea-level canal from that of the present lock canal. There is a somewhat smaller difference between a completely nuclear constructed canal and a conventionally constructed sea-level canal, the nuclear canal being the least vulnerable. This results from the great depth and width which nuclear construction provides. The sinking of a ship in a nuclear channel would not block it, as very likely would be the result in a conventionally excavated channel.

It has been argued that tidal gates would make a sea-level canal as vulnerable as the present lock canal. Such a view is not supported by the facts. The tidal gates proposed for controlling currents in a conventionally excavated sea-level canal are described in detail in Annex V, Study of Engineering Feasibility. They would be structurally simple rolling gates that could be moved laterally across the canal channel as needed. The canal could function for military purposes without the tidal gates, but they have been incorporated into the plans to reduce tidal currents to no more than 2 knots, a level at which experience indicates safe navigation is assured for commercial purposes. Sea-level canal experience is expected to show that faster currents can be tolerated and that the use of tidal gates could be diminished or possibly eliminated. If tidal gates were sabotaged while in use, they could be removed with no more difficulty than removing a sunken ship or blown bridge. Shipping could then continue to use the canal in somewhat faster tidal currents with some operational restrictions. Military destruction or sabotage of the tidal gates would have little effect on the

canal's use by combat vessels and by the relatively small ships used for logistical support.

DEFENSE REQUIREMENTS

With guerrilla action the most likely possibility, a concept of defense of a sea-level canal has been developed over the last several years. Initially, it was based on a precisely delineated buffer zone which would include the tactically important terrain features. Under continuing review the concept of a defense buffer zone has given way to a concept of access to critical areas for purposes of surveillance and defense, as required.

Sufficient forces to patrol and defend the canal against surprise attack will be stationed on the Isthmus. Under conditions of Limited or General War the necessary naval, ground, and air augmentation forces, adequate to meet the threat, would be brought in through prepared port and air base facilities at the site of the sea-level canal and those bases remaining in the Canal Zone. The permanently stationed defense forces vary between the canal sites considered. In general, these forces include airmobile infantry with their normal combat and service support elements. Air and naval forces would be positioned on or near the Isthmus as required.

COMPARISON OF DEFENSE CONSIDERATIONS OF THE ALTERNATIVE CANAL ROUTES

Each route has its own particular defense advantages and disadvantages when compared with the other routes. Some of these are purely military while others, being political or psychological in nature, would impact on the security of a sea-level canal.

Both Routes 10 and 14 are conventionally excavated in their entirety. Due to the cost of excavation the depth of these canals will be much less than that of a nuclear excavated canal. The nominal depth would be 75 feet. While it would be extremely difficult to close either a nuclear or a conventional canal by bombardment or even by an emplaced charge, the conventional canal is more vulnerable to blockage by the sinking of shipping in the canal. The nuclear canal is less susceptible to this type of blockage because of its great depth and width. The sinking of a ship in a nuclear canal would at worst only restrict passage, i.e., require a deviation in course or reduce speed at the point of sinking.

Route 10 has a major or even overriding advantage over Route 14. Construction of Route 10 would leave the present lock canal intact with its water supply unimpaired. If satisfactory treaty arrangements could be worked out, the lock canal could then be held on a standby basis to supplement or replace the sea-level canal in time of need. From the commercial and logistical standpoint this arrangement would represent a significantly increased canal transit capacity which possesses the potential for further growth, i.e., the conversion of the lock canal to a second sea-level canal.

Both Routes 10 and 14 have a unique vulnerability problem, the barrier dam. The problem is more pronounced on Route 14 than on Route 10, essentially due to the greater length and number of dams on Route 14. Detonation of one of these earth-filled dams

would cause severe canal flooding, bank erosion, and blockage of the canal by earth and debris. The barrier dams on Route 14 total 15 miles in length. In addition to the barrier dams, Route 14 has the problem of the Chagres River. The river will be diverted from its natural course into the canal. If its diversion dams were lost, the river would flow into the canal creating major navigation problems.

There will probably be fewer problems with the defense of Route 17 than either 10 or 14. The Zone presence will be smaller than at present, removing major United States forces out of the view of the Panama City/Colon populace. Over the life of the sea-level canal most defense facilities could be expected to move from the Zone bases to the Darien area as they become obsolete and maintenance costs require replacement.

Until the core borings from Route 17 were analyzed, this Route represented the nuclear option. It was selected to be constructed by nuclear excavation in its entirety. The boring revealed, however, that a 20-mile reach in roughly the center of the route is composed of weak clay shale which will not permit nuclear excavation of this section under the current state of the art for nuclear excavation. The AEC believes that with a sufficient future effort Route 17 could be designed so as to use nuclear excavations throughout its length. This effort would seek to answer such questions as: (1) The stability of nuclear crater slopes in clay shales; (2) whether gentle slopes in clay shales can be achieved by using some nuclear techniques such as the multiple base row-charge or subsidence crater (as opposed to the usual throw out crater), or by dressing row crater slopes with some inexpensive conventional earth moving technique, and (3) whether some modification to the alignment of Route 17 could reduce substantially the length or amount of the clay shales. Until the above mentioned developments are realized, however, Route 17 must be considered as a route utilizing both nuclear and conventional construction. As a combined route it loses its advantage of relative invulnerability to blockage by sinking of shipment in the channel. The varying lengths of the proposed canals affect the defense requirements. Routes 25, 23 and 8 are two to three times as long as the Panamanian routes. Routes 25 and 23 present a set of complex defense problems. In addition to its greater length, more than three quarters (80 miles) of the canal will have a dredged channel of 550′ x 75′ with the same relative vulnerability and defense problems as Routes 10 and 14. The nuclear portion of Route 25 which crosses the Continental Divide appears more susceptible to guerrilla attack than the corresponding part of Route 17, because of the greater width of the mountain range which constitutes the Divide on Route 25, 25 miles, as opposed to 15 miles on Route 17. Shipping in the conventionally constructed portion of Route 25 and the Colombian portion of Route 23 would be susceptible to attack by direct fire weapons from the hill mass which parallels this route almost continuously for 40-50 miles. The conventionally constructed portion would have almost no protecting lip or bank as the nuclear portion would. On the other routes the ridge lines are generally perpendicular to the canal and do not afford the vantage points of a parallel ridge. While there is a similar ridge on the Pacific end of Route 17 it is much shorter, of less elevation, and at greater range from the canal. Moreover, the canal on Route 17 would be protected to a significant degree by its 300 ft. nuclear ejecta lip and because of its greater depth would be much less easily blocked by sunken shipping.

The military issues applicable to a Colombian sea-level canal in general apply to Route 8. The negotiation of a canal defense base agreement with both Costa Rica and Nicaragua would be necessary in order to have a meaningful defense arrangement. Negotiation of such

defense agreements would be difficult and coordination of defense operations could be more complicated and difficult since three national interests would be involved. Route 8's principal advantage is its nuclear excavation and attendant lack of vulnerability, although this advantage is largely academic in that the cost of construction is all but prohibitive.

Overall the Nicaraguan-Costa Rican route does not appear to have any military advantage over the other canal routes which might mitigate the cost and construction disadvantages which caused the Commission not to pursue a more intensive site-survey-type investigation of this route.

CHAPTER IV

CANAL SECURITY AS A PART OF REGIONAL SECURITY

It is evident that the affairs of Latin America and the United States will continue to be bound up together for the foreseeable future. In addition to their geographic proximity, the two areas share many common bonds–economic, political and social. Transportation and communication technology, together with this community of interests, may be expected in the future to expand contacts between North and South America.

In addition to the shared interests just mentioned, North and South America share an interest in the security of the hemisphere and a need to foster the basic conditions which are conducive to the growth of political and economic stability and progress throughout the area.

To further these objectives an environment free from warfare must be preserved and to this end the states of the Western Hemisphere have created a community of nations to develop a cooperative approach to hemispheric security. The Inter-American Treaty of Reciprocal Assistance (the Rio Treaty) drafted in 1947, and the Charter of American States (Charter of Bogota) drafted in 1948 and recently amended, have resulted from our collective efforts.

The Charter of American States details the obligations of these states to maintain peace and security in the hemisphere and denies to any state or group of states the right to intervene directly or indirectly in the internal or external affairs of any other state. The Rio Treaty also provides for a collective defense against external threats to the security of the hemisphere.

A canal in Panama is an important element of hemispheric defense by the Rio Treaty countries and it is essential that it remain in friendly hands. Thus, canal defense is a key part of the security interest which the U.S. shares with Latin America. With advances of modern technology in the field of military weaponry canal defense can no longer be accomplished solely by defending the immediate area in and around the canal. Air and naval stations are necessary to extend the line of canal defense outward into the Atlantic and Pacific, and forces assigned the responsibility for canal defense must be prepared to operate in this modern environment.

Defense functions will be vital in the future for any of the sea-level sites under consideration. Properly performed, they will provide defense of the canal and thereby

contribute to the security of the entire region. The canal will thus continue to contribute to the ability of the Rio Pact nations to defend against aggression from outside the hemisphere.

CHAPTER V

EFFECT ON THE NATIONAL DEFENSE OF THE CHOICE OF METHOD OF CONSTRUCTION

This chapter discusses, from the military standpoint, indirect effects which the choice of method of construction may have on the national defense. This choice is directly related to the choice of site. Earlier chapters have already considered the advantages and disadvantages of alternative sites from the defense standpoint. The present chapter examines less direct effects, such as the drain on United States construction capabilities, risk of closure of the present canal during the construction of the new canal, and technological advances with military utility.

BASIC DATA ON CONSTRUCTION ALTERNATIVES

Two general methods for constructing a sea-level canal are currently under consideration: one using mechanical excavators to accomplish all the excavation, and the other using a combination of nuclear explosions to excavate part of the main navigation channel (and possibly part of the flood control system) and mechanical excavators to excavate the remainder.

DRAIN ON CONSTRUCTION CAPABILITIES

Construction of a sea-level canal would not significantly affect the national defense of the United States by diverting construction effort, both personnel and materiel.

Personnel

Conventional Construction. The construction on Routes 10 and 14, the routes considered for construction entirely by conventional methods, would require about 7,000 people, the majority of whom probably would be employed by civilian contractors. The requirement for government management personnel in key positions is roughly 50 men. The project would require the services of 30-50 outstanding consultants in the fields of management, design and construction, employed on a part-time basis. The government design and design support staff required for a project of this size would number about 600 people, including support groups, such as construction support, supply personnel and finance, and field personnel, such as survey crews. At peak strength the construction force in the field would have the following strength:

Government supervision	400
Contractor personnel	6,000
Medical personnel	200

These numbers compare with the following data on contract employees, in millions, engaged in construction in the United States:

	1965	1966	1967	1968	1969*
All Contract Construction	3.19	3.28	3.21	3.27	3.40
General Building Contractors	.99	1.03	.98	.99	1.02
All Heavy Construction Contractors	.65	.67	.66	.68	1.73
Highway & Street Contractors	.32	.32	.31	.32	.32
Other Heavy Construction Contractors	.32	.35	.35	.36	.40

*Estimated on basis of incomplete data for the year.

In 1968 the total number employed in heavy construction and highway and street work was 2,450,000. In a "worse case" situation, it is assumed that the approximately 7,000 workers needed on canal construction were all United States personnel. This would mean that less than .3% of the total United States construction force was involved. The "worse case" does not represent a significant diversion of capability from a national defense standpoint and, moreover, it is unlikely to occur as a considerable portion of the work force will most probably be indigenous to the host country.

Nuclear Construction. The construction of Routes 17 and 25 by nuclear construction methods will reduce the numbers of contractor personnel required to about 4,000, but would raise the skill level over that required for conventional construction only. The management requirements will remain basically the same as those for conventional construction. The number of consultants would be increased to a total of 50-60 to furnish consultants in nuclear as well as conventional fields. The design and support staff would require about 700 people for Route 17 and 1200 for Route 25. These numbers would include people qualified in conventional construction as well as people trained in nuclear excavation design. At peak strength the construction effort would involve the following people in the field:

Government supervision	395
Contractor personnel (Route 17)	4,000
Contractor personnel (Route 25)	5,000
Medical personnel	250

While the number of personnel involved for the nuclear construction alternatives is

smaller than for conventional construction, the demand for highly trained and experienced specialists from the nuclear energy field would probably be more significant from the standpoint of national defense than the overall numbers of people involved in any of the alternatives.

Materiel

Some idea of the possible drain on construction materiel can be obtained by comparing the dollar cost of construction in the entire United States.

Conventional Construction. On the basis that Route 10 could be constructed in 14 years, the average annual contract costs would be about $200 million. Assuming the peak year contract cost to be half again that of the average year, the peak year construction contracts would be approximately $300 million. The estimates compare with the following construction data for the United States ($ billion):

	1965	1966	1967	1968	1969*
Total New Construction Put in Place	$72.3	$75.1	$76.2	$84.7	$88.0
Total Private	50.2	51.1	50.6	57.8	62.0
Total Public	22.1	24.0	25.6	27.7	26.0
Heavy Construction	17.4	19.2	19.9	20.8	23.3

*Estimate is based on incomplete data for the year.

The peak year amount given above for canal construction would be .4% of the total 1969 construction, 1.2% of total 1969 public construction, and 1.3% of 1969 heavy construction. Route 14 would require 16 years to construct at a slightly higher cost.

Because Routes 10 and 14 consist mostly of excavation, demand on construction materiels is expected to be modest. An exception is chemical explosives of which possibly a million tons may be used during the construction period. Special manufacturing provisions may be required to supply this increased demand.

Conventional construction requires large amounts of specialized equipment which must be delivered in a relatively short period of time before construction is started. This equipment will probably be specifically designed for the project and might consist of a substantial number of special earthmoving machines and several large dredges.

Nuclear Construction. The nuclear routes may be less costly and take equal or less time than converting the existing canal to sea-level operation. Thus, the national defense implications of diverting construction effort would be even less than for converting the existing canal by conventional means. The requirement for specialized equipment, such as large diameter drilling equipment, and the need for advanced procurement orders must be recognized.

Nuclear construction of Route 17 and Route 25 would require about 250 and 150 nuclear explosives respectively, with a total yield for both in the range of 120 megatons.

The amount of fissionable and thermonuclear materiel required for this number of explosives would be small compared to the total United States stockpile and therefore would not have any unfavorable national defense implications. Special manufacturing facilities may be required to fabricate the explosives themselves.

TECHNOLOGICAL BENEFITS

Conventional Construction

Construction of a sea-level canal by conventional means would produce technological benefits primarily in the field of excavation equipment and techniques. A project of this size and magnitude would use the most modern equipment and methods. Machinery of novel design could be used and would be specifically adapted to the canal excavation. The experience and advances in technology gained thereby would be useful not only in civil projects involving large quantities of earth moving, but also in military projects of a similar nature.

The experience gained by engineers engaged in such construction has a carry-over into civil and military fields in the areas of planning, organization, and execution of projects of large scale which require the coordinated efforts of many engineering and administrative agencies.

Nuclear Construction

The development of nuclear excavation technology which must precede nuclear construction of a sea-level canal would probably be of greater significance to the national defense than any other indirect effect discussed in this chapter. The technological benefits could be greater than from the use of conventional earthmoving methods.

Beyond the development of technology, the development program and the construction of a sea-level canal by nuclear means would result in increasing the United States pool of trained and experienced people in an important area of the nuclear energy field.

CLOSURE OF THE PRESENT CANAL

Depending on the plan finally adopted, conventional construction of a sea-level canal along Route 14 might involve risk of accidental closure of the present canal, as well as deliberate closure for some limited period of time, in effecting the changeover of sea-level from the present level of Gatun Lake, 82-87 feet above sea level. The deliberate closure for short periods of time (currently estimated at 30 days), accurately forecast in advance, would not have serious defense implications.

The risk of accidental closure stems from the possibility that excavation in or near present slopes may result in an unstable condition which would lead to a major landslide blocking the present lock canal or the sea-level canal after conversion. Depending on the magnitude of such a slide, it could close the interoceanic waterway to traffic for a period of

months. If Gatun Lake were emptied, the lock canal could be out of operation for as long as two years. The denial of the canal to both defense and commercial shipping for such a period could have a serious adverse effect on the national defense.

A major advantage of Route 10 over Route 14 as the route for a conventionally excavated canal is the fact that Route 10 can be constructed without risk of interference with the traffic in the existing canal. Route 10 is located approximately ten miles west of the existing canal, a sufficient distance to preclude canal closure by accident. It would also preclude the planned closure for changeover.

THE ATLANTIC-PACIFIC INTEROCEANIC CANAL STUDY COMMISSION

Annex III
Study of Canal Finance

ANNEX III

REPORT OF THE STUDY GROUP

ON

CANAL FINANCE

Submitted to
The Atlantic-Pacific Interoceanic Canal Study Commission
October 1970

REPORT OF THE STUDY GROUP

ON

CANAL FINANCE

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Chapter I

INTRODUCTION

Purpose of the Study

In October 1965, the Secretary of the Treasury, at the request of the Atlantic-Pacific Interoceanic Canal Study Commission, agreed to provide the Chairman for an interdepartmental study group to assess the financial feasibility of a new, sea-level Isthmian canal and to examine alternative methods for financing the construction and operation of such a canal. Mr. R. Duane Saunders, then the Director of the Office of Debt Analysis and subsequently Assistant to the Secretary (Debt Management) until July 1969, was initially assigned responsibility for this task. In July 1969, Mr. Edward P. Snyder, Director of the Office of Debt Analysis, became Chairman of the Study Group.

The purpose of the Canal Finance Study was described by the Commission as follows:

> To examine the methods available for financing the construction and operation of a sea-level canal; and in cooperation with other agencies and the Commission, to analyze the implications of each approach. In the ultimate sense, the purpose of the Canal Finance Study is to provide comparative analyses of the economic and financial costs of alternative canal proposals so that the Commission can give appropriate weight to these costs of the various alternatives in arriving at its final recommendation. The narrower objective is to develop a feasible plan for the financing of the recommended alternative.

Scope of the Study

The Commission's instructions to the Canal Finance Study Group were incorporated in a nine point topical outline:

1. Is it possible to finance a sea-level canal through tolls?
2. What sources of finance are feasible?
3. What are the alternative methods of financing a sea-level canal?
4. Priority of payments on capitalization.
5. What related costs should be included in the analysis?
6. Residual interests.
7. Construction and operating costs.
8. Net revenue available.
9. Financial plan.

The Canal Finance Study Group undertook to examine only those issues which might have a direct bearing on the financing of the construction and operation of sea-level and other canal options under consideration. Within this relatively limited framework,

examination of the economic and financial implications of the canal options has involved an analysis of the results of the other Commission studies, particularly the construction and operating cost estimates developed for the Study of Engineering Feasibility and the projected traffic and revenue estimates contained in the Study of Interoceanic and Intercoastal Shipping.

The Study Group did not attempt to evaluate (1) the effects of a new canal on the economies of (a) the potential host countries (b) the United States or (c) third party countries, (2) foreign relations benefits or costs (except for the costs of directly related payments to the host country), or (3) national defense values of a sea-level canal. These matters fall more directly within the purview of other study groups, and the Commission has concluded, in coordination with these study groups, that quantitative dollar values cannot be placed on the non-revenue benefits and burdens attributable to a new interoceanic canal. Exclusion of these broad questions from the Finance Study limits the overall value of the Study. In particular, a complete economic evaluation of a sea-level canal project requires that judgments be made on the foreign policy, defense and other values and costs associated with a particular decision.

The primary analyses of the economic and financial implications of the canal options in this Study are limited to the evaluation of Routes 10 and 14 Separate in Panama, for which conventional excavation is assumed. The addition of a third lane of deep-draft locks to the present Panama Canal and continued operation of the present canal also are considered but in less detail. Route 25 in Colombia, involving nuclear excavation along the portion that traverses the Continental Divide, has not been analyzed, largely because of uncertainties concerning the feasibility of nuclear excavation at the present time.

This Study treats only with costs and revenues directly associated with transiting ships between the oceans. An organization concerned with building, operating, and maintaining new canal facilities may have other commercial activities. No costs or revenues from any such activities have been included in the analyses in this Study.

Within its limited scope, the basic question which the Finance Study attempts to answer is whether any of the alternative proposals would be a commercially feasible venture. The costs and revenues associated with the various canal options were examined to determine whether the additional revenues which would be earned by the new facilities would be sufficient to recover their capital and operating costs. This analysis is characterized as the "economic evaluation." Also examined were assumptions under which the books of account of a canal operating agency would show a recovery of costs after 60 years of operation. This examination involved analysis of various combinations of revenues to be credited to the agency at different toll rates, reimbursable costs to be charged against the agency, and rates of interest charged the agency on its reimbursable capital. This is identified as the "payout analysis."

A detailed financial plan, which was an original objective of this Study, would necessarily incorporate factors that include the final recommendations of the Commission as to whether and when additional facilities should be constructed, the terms of any new treaty agreements, and any revision in the tolls system. The general circumstances under which additional facilities would be commercially feasible, or under which self-liquidating financing could be anticipated under the payout analysis, are broadly included.

Since costs would be incurred over a period of years and revenues also would be realized over a period of years, they must be placed on a common basis for comparative purposes. This is done by discounting future costs and earnings to a common date using appropriate interest rates for this purpose.

To permit rapid revision of the economic and financial analyses as new data on costs and revenues were received, a number of computer programs were developed so that new variables could be introduced for machine analysis. The results are presented graphically and in tabular form to show the impact of changes in variables.

Study Presentation

Chapter II summarizes the estimates of costs and revenues derived from the Study of Engineering Feasibility and the Study of Interoceanic and Intercoastal Shipping, respectively. Chapter III provides analyses of alternative canal proposals, presenting both the "economic evaluation" and the "payout analysis." Chapter IV discusses alternative methods of financing. Chapter V presents conclusions derived from the economic evaluation and the payout analysis.

Chapter II

COST AND REVENUE ESTIMATES

Introduction

This Chapter summarizes the basic estimates of construction costs, operating expenses, and revenues from projected interoceanic canal traffic upon which the economic evaluation and payout analyses in this Study are based. The construction cost estimates, obtained from data developed for the Study of Engineering Feasibility, are based on evaluation of data from field surveys, previous reports, and engineering design studies. The revenue estimates from the Study of Interoceanic and Intercoastal Shipping are based on two estimates of the growth of cargo tonnage.

Cost Estimates for Canal Options

Figure II-1 diagrams the routes considered in the sea-level canal investigation. Based on a comparative analysis of all the sea-level canal routes, the Study of Engineering Feasibility concluded that Route 10 in Panama was the most desirable for a sea-level canal from an engineering standpoint and that Route 14 Separate (14S) in the Canal Zone was the next most desirable alternative. It was also concluded that, if nuclear excavation should become feasible, Route 25 in Colombia would be the least expensive sea-level canal alternative. The Study of Engineering Feasibility also developed cost estimates for Route 15, the designation given to an improved lock canal along the existing Panama Canal alignment. These estimates are based essentially on adding a lane of deep-draft locks to the present lock canal.

All conventionally excavated sea-level canals would be designed for alternating one-way convoy traffic and would have a single channel 550 feet wide, with a parabolic bottom 75 feet below mean sea level at the edges and 10 feet deeper along the center line. A channel of these dimensions would be able to accommodate ships of 150,000 deadweight tons (DWT) under all conditions, and ships of 250,000 DWT under selected favorable conditions. Ocean approaches would be 1,400 feet wide and 85 feet deep, suitable for two-way traffic. The plans include provisions for gates to control tidal currents induced by tides, when necessary. A tug boat fleet would also be provided to assist navigation through the canal. Necessary supporting facilities such as roads, anchorages and buildings were also included in the cost estimates. Because essentially all of the military installations needed for the defense of a sea-level canal within Panama could be adapted from existing installations in the Canal Zone, the additional costs for this purpose would be small and are not included in the cost estimates.

The estimates of costs of continued operation of the existing lock canal include an allowance for the cost of the Canal Zone Government, which amounted to $23.4 million in

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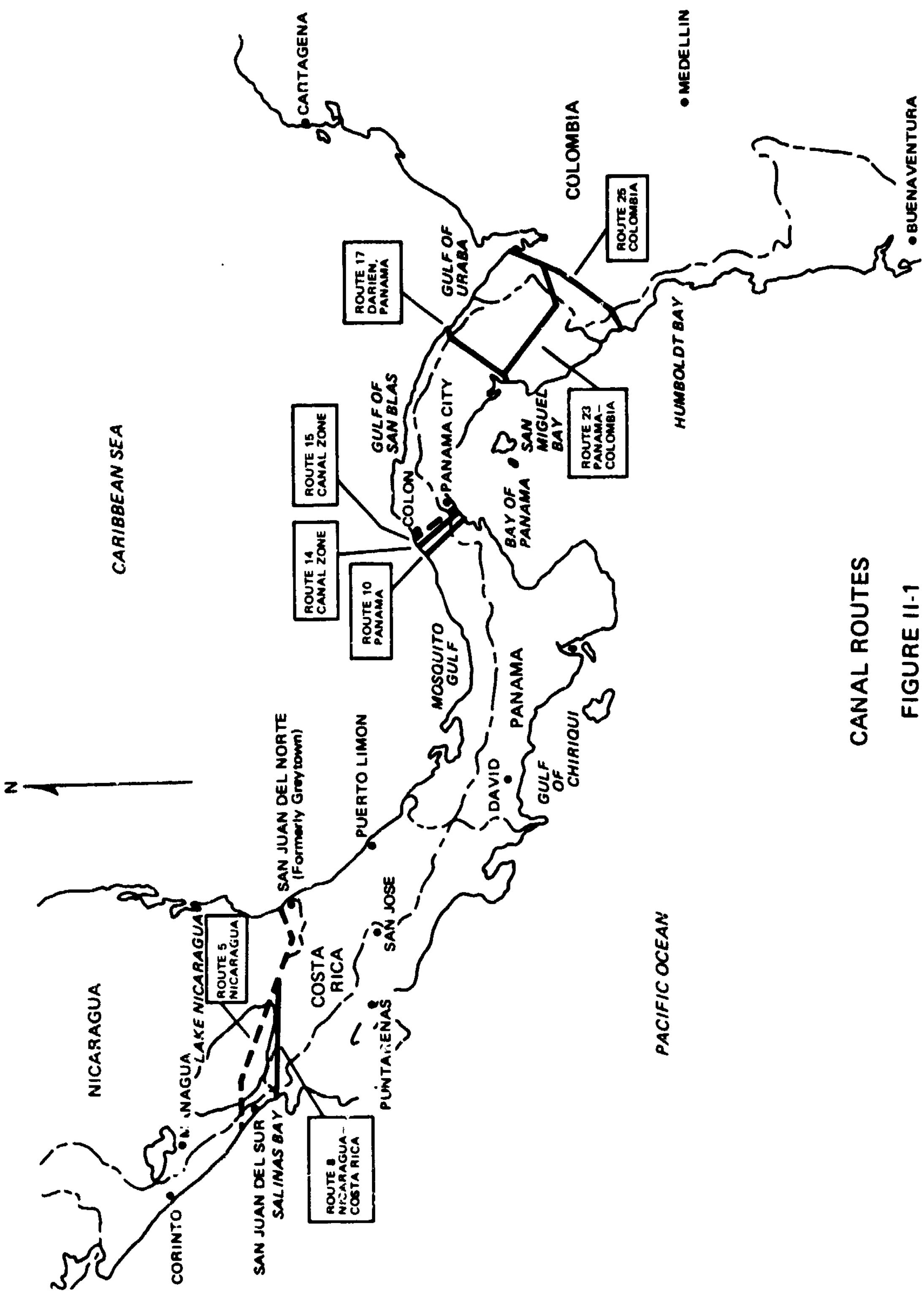

CANAL ROUTES

FIGURE II-1

fiscal year 1969. The cost estimates for the sea-level canal options do not include such an allowance on the basis that reduced U.S. personnel requirements and a greater reliance on local personnel would reduce such costs. To the extent that some Government functions are found necessary for sea-level canal operation, the analyses in this Study may overstate the economic and financial feasibility of the sea-level canal options.

Route 10

Route 10 crosses the Panamanian Isthmus through generally low-lying country about 10 miles southwest of the existing lock canal. The land cut, which would intersect portions of Gatun Lake, would be 36 miles long. The ocean approaches would be 17 miles long. The maximum elevation in the area to be excavated is about 430 feet. Compared to other routes it has several advantages, such as short length, easy accessibility, low elevations, and little need for supporting facilities beyond those already available at the Panama Canal. These advantages are all reflected in the relatively low estimated construction cost for Route 10.

The Engineering Feasibility Study concluded that a conventionally excavated single-lane sea-level canal on Route 10 would cost about $2.88 billion to design and construct; this cost includes provision for tugs which are needed for the safe operation of the canal. The funds would be expended approximately as follows during the 14 years required for completion:

Year	Funds required ($ millions)
1	11
2	11
3	54
4	152
5	253
6	306
7	306
8	298
9	257
10	257
11	275
12	267
13	250
14	183

Cost of operation and maintenance of a sea-level canal on Route 10 would amount to $35 million a year plus $640 per transit. This includes all costs associated with tugs which would accompany most ships.[1]

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[1] Since tugs are essential for the safe transit of ships through the canal, tug service as required was assumed to be an integral part of the services furnished for the tolls paid by all ship operators. This differs from present Panama Canal practice in which tugs are provided as required by canal operating rules, but individual ship operators are charged for the tug services in addition to tolls.

Certain of the facilities furnished as a part of the original sea-level canal construction would require replacement before the end of the period for which the finances of the canal are being examined. The year when the replacement is required and its estimated cost are tabulated below:

Year after opening replacement is required	Estimated cost of replacement, $ millions	Annual depreciation expense, $ millions
25	3	.1
30	18	.6
40	44	1.1

Upon opening of the sea-level canal for full operation, it was assumed that the Panama Canal would be placed in a stand-by status for about 10 years to provide a transit facility in case of interruption to traffic in the sea-level canal on Route 10. To maintain the lock canal in a status of limited operational readiness would cost about $4 million a year. After 10 years, the lock canal would be mothballed at an estimated cost of $1 million, and maintained in this status at a cost of about $1 million a year.

The transit capacity of the sea-level canal on Route 10 would be at least 38,000 passages a year. The capacity could be increased to 56,000 transits a year or more by the addition of a centrally located by-pass. The by-pass would cost $460 million and would take about four years to construct. Operation and maintenance cost would decrease about $1 million a year because of improved efficiency of operations.

Route 14S

This route lies wholly within the present Canal Zone and follows closely the lock canal alignment. It takes advantage of excavations made for the Third Locks Project in 1939-1942. The land cut, which would traverse the widest part of Gatun Lake, would be 33 miles long. The ocean approaches, including the reach across Limon Bay, would be 20 miles long. The maximum elevation in the area to be excavated is about 450 feet. Route 14S generally enjoys the advantages of Route 10 but its construction would interfere with operations in the lock canal, increase the risk of causing slides into the lock canal which might block the canal for traffic, and eliminate future use of the lock canal as a temporary alternative or an addition to the sea-level canal.

The cost of construction of a canal along Route 14S is estimated to be slightly more than that for Route 10. Route 14 with the cut through the Continental Divide separated from the present canal would cost about $3.04 billion for design and construction including

the cost of tugs. Funds would be expended approximately as follows during the 16 years required for completion:

Year	Funds required ($ millions)
1	11
2	11
3	40
4	179
5	321
6	366
7	364
8	317
9	284
10	262
11	250
12	215
13	140
14	121
15	91
16	68

Fixed operation and maintenance cost, the additional cost per transit, and the schedule and cost for major replacements would be the same as for Route 10. Route 14S would divide and lower Gatun Lake, and thus preclude the use of the Panama Canal as a standby for the sea-level canal. Accordingly, no costs for standby operation or mothballing the Panama Canal were included in the analysis of Route 14S.

The capacity of Route 14S would be at least 39,000 transits a year. Capacity could be increased to 55,000 transits a year or more by shortening the length of the restricted cut. This would cost $430 million and require four years for construction. Operation and maintenance cost would be reduced about $1 million a year because of improved efficiency of operations.

Route 25

This route lies wholly within Colombia and generally parallels the Panama-Colombia border. The total land cut is 98 miles in length; the ocean approaches are five miles long. The disadvantages of long length and lack of existing supporting facilities would be more than offset by the expected savings if nuclear excavation were technically feasible at an estimated cost of $2.1 billion. Route 25 is not included in the economic evaluation or payout analysis largely because of the uncertainties surrounding nuclear excavation.

Route 15

The Route 15 option analyzed in this Study consists of the new plan for adding deep draft locks to the Panama Canal described in the Study of Engineering Feasibility. In

addition to new large locks, the plan includes widening and deepening channels, augmenting the lockage water supply, and other features. These improvements would cost $1.53 billion, would be capable of handling ships up to 150,000 DWT, and would provide for a total transit capacity through the improved canal of 35,000 ships a year. The approximate annual expenditures for the 10 years required for construction are tabulated below:

Year	Funds required ($ millions)
1	10
2	20
3	100
4	200
5	220
6	220
7	220
8	220
9	220
10	100

In addition to the cost of operation and maintenance of the present canal, the operation and maintenance of the deep draft locks would cost $13 million per year. There would also be an additional cost of $1,600 per transit for all transits over 26,800 a year. This amount includes $800 per transit for pumping lockage water. There would be no separate charge against canal users for these costs. Tug charges, about $0.024 per cargo ton, would be in addition to these costs. Consideration would also have to be given to the possible replacement of the existing locks.

Continued Operation of the Present Panama Canal

An alternative to building a sea-level canal is the continued operation of the Panama Canal. It has been estimated[2] that the present canal can accommodate 26,800 transits a year provided improvements at an estimated cost of $92 million are undertaken. The tonnage estimates in the Shipping Study suggest that the demand for transits, at the existing toll levels, could reach 26,800 annual transits as early as 1990.

Estimated annual cost of operating and maintaining the lock canal from 1971 to 2000 is indicated in Table II-1, based on information provided by the Panama Canal Company. Annual costs range from $79 million to $92 million over the period in constant dollars and include the costs of the improvement program proposed in the Kearney Report.

The debt on which the Panama Canal Company pays interest to the U.S. Treasury amounted to $317 million as of June 30, 1970. In certain of the evaluations this $317 million has been used as the indebtedness of the Panama Canal Company. However, it

[2] "Improvement Program for the Panama Canal, 1969", A.T. Kearney and Company, Inc.

TABLE II-1
Annual Cost of Operating and Maintaining The Panama Canal
(millions of dollars)

Year	Approx. Annual Transits	Current Cost	Depreciation on Improvements	Operation of Improvements	Added Pilotage	Total Cost
1971	15,500	75	–	–	–	79
1975	17,000	75	–	–	1	80
1980	19,000	75	1	2	2	83
1985	21,000	75	1	4	2	86
1990	23,000	75	2	6	2	89
1995	25,000	75	2	8	2	92
2000 (and after)	26,800	75	2	8	2	88

should be pointed out that, as of the same date, the total unrecovered United States investment in the Canal, including unpaid interest accrued since 1903, was estimated by the Company to be $700 million, excluding defense costs.

The present canal has been in operation for 56 years. As a result of continuous maintenance and improvements the canal continues to be in excellent condition capable of being operated for many years. It is not known, however, whether or when the existing locks might require replacement. The cost of such replacement has not been estimated but an approximate cost of $800 million has been used for evaluation purposes. Construction has been assumed to take six years. Transit capacity would remain at 26,800 a year (with the improvements recommended in the Kearney Report).

Treaty Cost and Land Use

The cost of real estate acquisition and easements has been estimated for the various routes as indicated below:

Route	Cost of Real Estate $ millions
10	27
14S	2
15	0

No lump sum settlement cost with the host country for land use is included in the analysis since royalties are assumed to provide the entire reimbursement to the host country.

Forecasts of Cargo Tonnage and Transits

The Shipping Study presents two forecasts of cargo tonnage through a sea-level canal. The two estimates are called the "potential tonnage" forecast and the "low tonnage" forecast (Figure II-2). The potential tonnage forecast is considered reasonable by the Commission, but with recognition that no forecast for so long and distant a period can be relied upon unequivocally. The low tonnage forecast provides for possible lower future traffic and has been adopted by the Commission for determining financial risks. The projected tonnage for the two estimates is summarized below for bench-mark years:

	Projected cargo in millions of long tons	
Year	**Potential Forecast**	**Low Forecast**
1970	111	111
1980	157	171
1990	239	218
2000	357	254
2020	643	325
2040	778	403

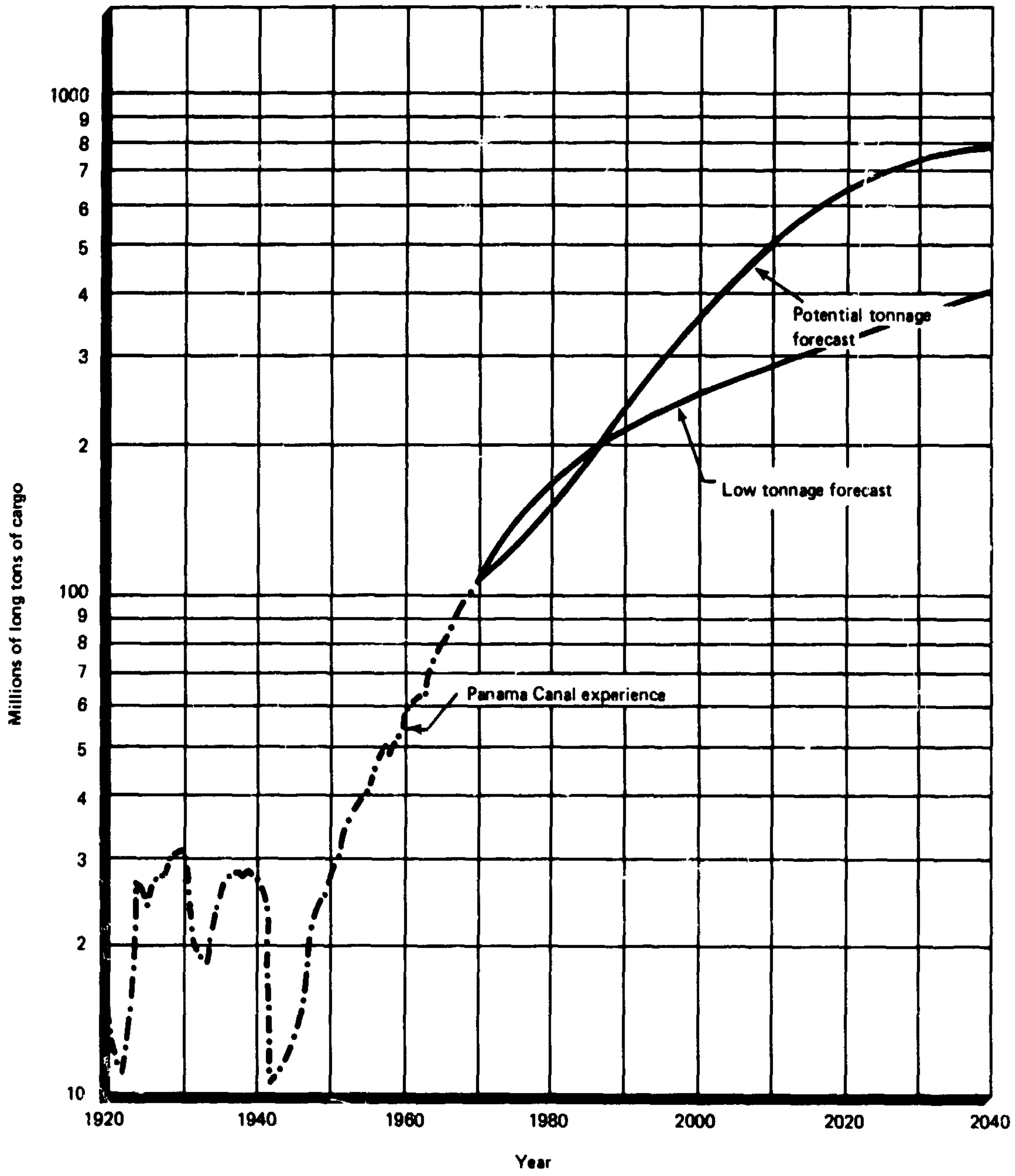
For the purpose of estimating transit requirements, the Shipping Study developed a range of possibilities concerning the cargo distribution of the future among freighters, dry bulk carriers and tankers. A methodology, which included consideration of projected ship characteristics of future interoceanic canal traffic, was employed to convert the projected cargo mix into a projection of transits for canal capacity planning and revenue projection purposes. It was concluded that the future mix of ships carrying cargoes through a sea-level canal could range from the present experience of the Panama Canal, in which 46% of the cargo tonnage is carried in freighters and 54 percent in dry bulk carriers and tankers, to a much higher ratio of bulk carriers and tankers by the year 2000 and thereafter, i.e., 75% with only 25% of the cargo tonnage moving in freighters. For revenue projection purposes the 46 percent freighter cargo mix was used with the low tonnage forecast, and the 25 percent freighter cargo mix with the potential tonnage forecast.[3] Table II-2 shows the range of forecast transits associated with the forecasts of cargo tonnage and cargo mix.

Projected Revenues

Revenue computations in the Shipping Study were derived by converting current Panama Canal revenue experience to an average toll per ton of cargo for each type ship and by weighting according to estimated cargo distribution among the types of ships. Thus, tolls are stated in terms of dollars per cargo ton as an expedient for relating cargo tonnage and cargo mix to gross revenues.

Tolls for the existing Panama Canal are levied on the basis of the Panama Canal ton which consists of 100 cubic feet of cargo carrying space. Laden ships pay $0.90 per ton and ships entirely in ballast $0.72 per ton. Certain other ships pay $0.50 per displacement ton. The present tolls system produces gross revenues which currently average approximately

[3] If the higher tonnage were realized, it would presumably include a much higher proportion of bulk commodities moving on larger ships and a lower proportion of freighter cargo.



ISTHMIAN CARGO TONNAGE: ACTUAL AND PROJECTED

FIGURE II-2

TABLE II-2
Projected Transit Requirements
For A Sea-Level Canal [1]

Year	Total number of transits "Potential" tonnage[2]	"Low" tonnage[3]
1970	15,500	15,500
1980	17,300	20,900
1990	21,000	24,300
2000	24,500	26,000
2020	37,800	29,100
2040	39,300	31,500

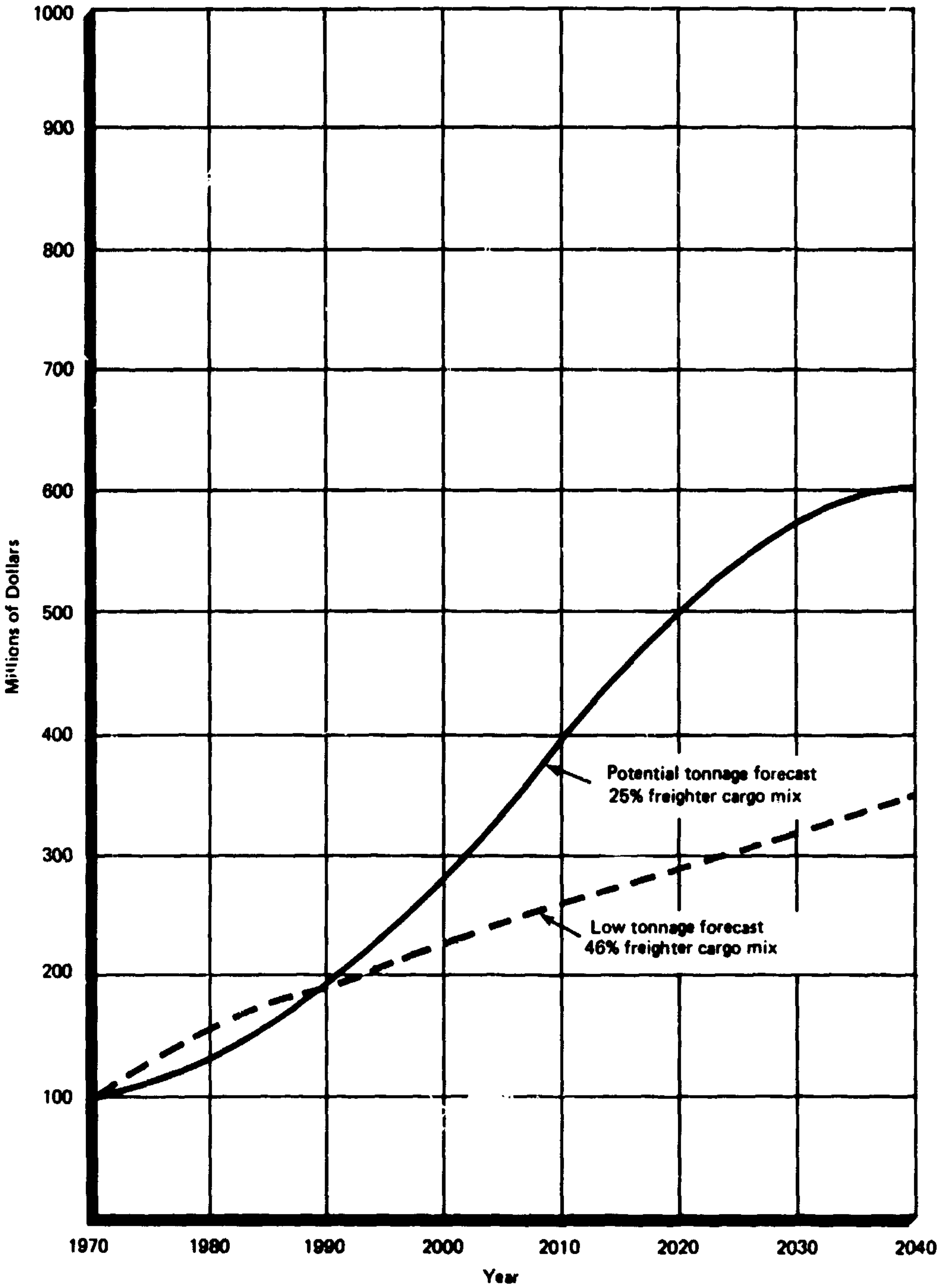
[1]For a canal which can accommodate ships up to 250,000 DWT.
[2]25% of cargo in freighters.
[3]46% of cargo in freighters.

$0.884 per long ton of cargo. Bulk cargoes produce less than average revenue per cargo ton, and a trend toward increased proportion of bulk cargo would result in a lower gross revenue per ton of cargo transited under the current toll assessment system. The 25 percent – 75 percent ratio projected in the Shipping Study would produce gross revenues averaging approximately $0.777 per ton of cargo under the present system.

Figure II-3 shows projected revenues under the present Panama Canal toll assessment system. The projected revenues depicted in Figure II-3 are based on the Shipping Study estimated average toll rates of $0.884 per cargo ton for the "low" tonnage, 46% freighter cargo mix forecast, and, reflecting the declining proportion of freighter cargo, $0.884 declining on a uniform annual basis to $0.777 per cargo ton in year 2000 for the "potential" tonnage, 25% freighter cargo mix forecast.

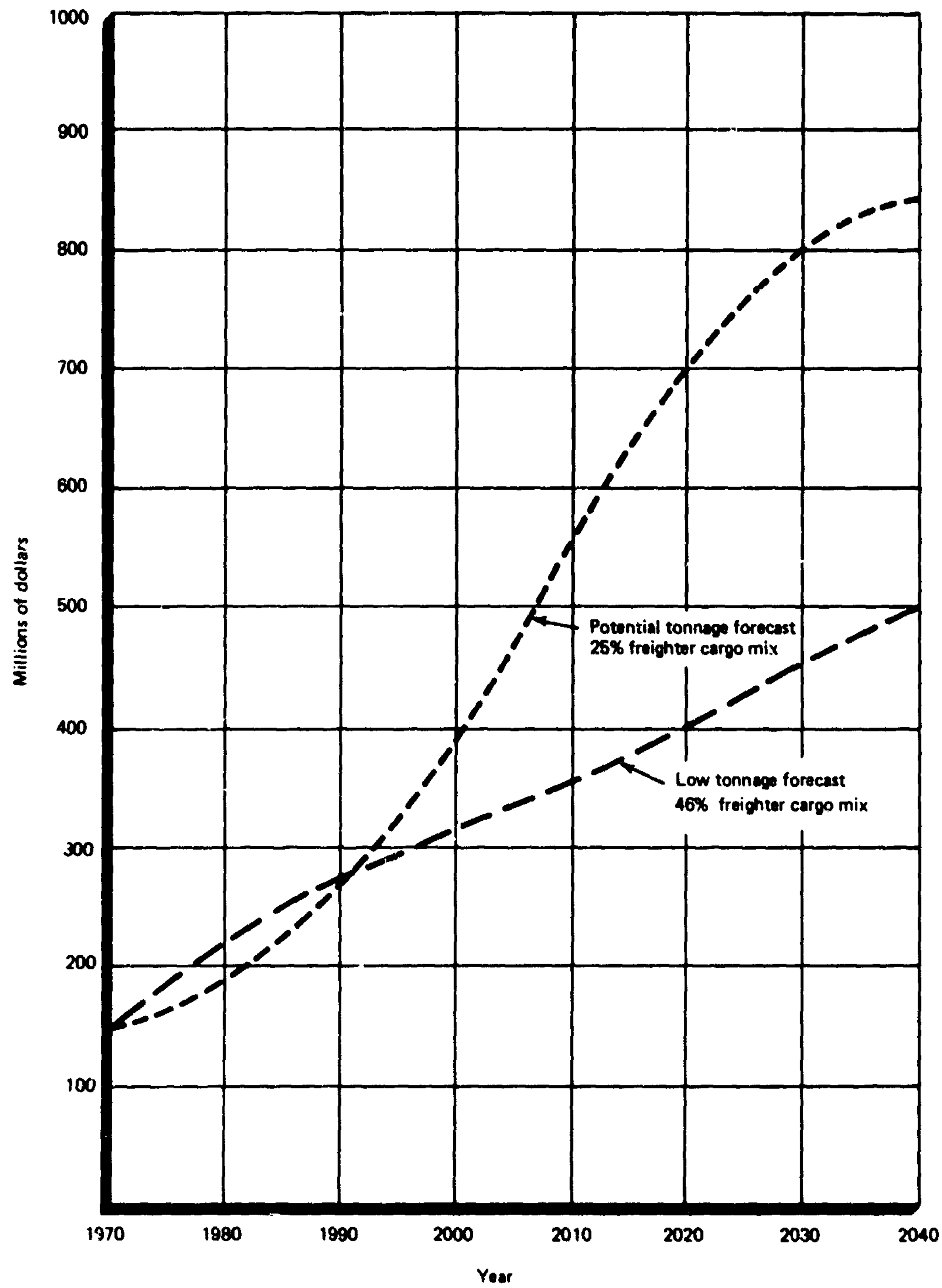
The Shipping Study also concluded that a restructured assessment system could produce approximately 40 percent greater revenues from an average tolls increase of 50 percent, without markedly affecting the traffic growth expected under the present Panama Canal tolls sytem. This restructured system would involve selective increases of as much as 150 percent on some cargoes and reductions below the present levels for some bulk cargoes. Figure II-4 shows projected revenues under the restructured assessment system discussed in the Shipping Study, assuming the restructured system had been put into effect at the beginning of 1970. The projected revenues related to the restructured tolls system in Figure II-4 are based on the same computations as for Figure II-3 but with 50% higher revenues for year 1970 declining gradually to 40% higher revenue in year 1990.

The projected average tolls per ton of cargo, using the existing Panama Canal toll rates and structure–which produces $0.884 per cargo ton for the 46% freighter cargo mix and $0.884 declining to $0.777 in the year 2000 with a decline to 25% in the freighter cargo



PROJECTED REVENUES BASED ON CURRENT PANAMA CANAL TOLLS SYSTEM

FIGURE II-3



PROJECTED REVENUES BASED ON RESTRUCTURED TOLLS SYSTEM

FIGURE II-4

mix– form the basis for the revenue estimates that are included in the economic evaluation in this Study. The payout analysis, on the other hand, assumes a toll structure that produces a constant revenue per cargo ton without regard to the proportion of freighter, dry bulk, and tanker cargoes and uses a toll rate of $0.884 per cargo ton (the current average revenue per ton from total Panama Canal traffic) at least until initiation of construction or opening of a new canal.

Payments to Host Countries

The 1955 Treaty with Panama provided for a fixed $1,930,000 annuity to Panama. The 1967 draft treaty would have substituted royalty payments for each long ton of cargo transported through the canal, starting at 17 cents per long ton of cargo upon ratification of the new treaty and rising 1 cent annually for five years to 22 cents per long ton where it would remain thereafter.

The Study Group has assumed the following royalty rates for its financial evaluations.

Year	Royalty rate per ton of cargo transited
1971	$0.17
1972	0.18
1973	0.19
1974	0.20
1975	0.21
1976 and after	0.22

Chapter III

ANALYSIS AND EVALUATION

Introduction

General

This Chapter presents and summarizes the analysis of the economic and the financial implications of various canal options. Two basic approaches are involved in the analytical process – one designated as the "economic evaluation" and the other as the "payout analysis." These two analyses are distinguished by the specific questions toward which each is directed. Economic evaluation attempts to provide a measure of the worth to the Federal Government, or to the Nation as a whole, of a proposed investment project. Payout analysis, on the other hand, relates to the books of account of a proposed project, i.e., the extent to which capital costs, operation and maintenance expense, royalty and other costs charged to an assumed project operating agency could be recovered from revenues and credits assigned to the agency. Both approaches, although directed to differing objectives, may be pertinent to the Commission's findings and recommendations.

As an example of the application of both procedures, prior to project approval Federal water resources projects are generally subjected to a thorough examination of the total benefits which would be created by the project and the costs which would be attributable to the project. The procedures for conducting these analyses have been formalized in "Policies, Standards, and Procedures in the Formulation, Evaluation, and Review of Plans for Use and Development of Water and Related Resources",[1] and made applicable to the various Federal agencies involved in water resources project planning and development. Senate Document No. 97 provides for consideration of all benefits attributable to the project, whether or not these benefits generate revenues for the project.

Assuming a favorable outcome of the economic evaluation, indicated by benefits at least equal to costs either on a present value or annual equivalent basis, the proposed project may be subjected, where applicable, to a payout analysis in order to determine whether revenues assigned to the project would be sufficient to amortize the reimbursable portion of construction costs. A favorable outcome of both the economic evaluation and the payout analysis (if one is conducted) has generally been a prerequisite to project approval by the Congress.

The Commission requested that the Finance Study Group consider only the potential financial returns of the canal options under consideration. A complete benefit-cost analysis,

[1] Reprinted and popularly referred to as Senate Document No. 97 (87th Congress, 2nd Session).

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however, would take into account foreign policy, defense, and other benefits and burdens which might be attributable to a canal investment, including what the Commission considers to be the unique role of an interoceanic canal in the American Isthmus as part of the world-wide transportation system. In this connection, Federal budgetary procedures regularly require estimates of the dollar value of all benefits and all burdens. However, in the case of the interoceanic canal investigation, the Commission has concluded that no quantitative dollar values could be placed on the non-revenue benefits attributable to a new interoceanic canal; nor could all the burdens of such a canal be identified or quantified. Accordingly, the Finance Study Group has applied the procedures generally prescribed for Federal project economic evaluation using only toll revenues and credits as benefits, and estimated construction and other identified costs as burdens. Notwithstanding these fundamental limitations, this analysis is hereafter referred to as the "economic evaluation."

To properly reflect the benefits and costs for the Nation as a whole, only the incremental benefits and costs are relevant. Because the Finance Study considers only revenues as benefits, the question of the financial return from the viewpoint of the Nation as a whole depends upon whether the additional revenues which would be earned as a result of any new investment, over and above the net revenues which would be earned by the existing lock canal, would be sufficient to cover the costs of operating and maintaining the new facilities and to amortize the capital investment with an appropriate rate of return. While this statement of principle seems easy and straightforward, its application may be difficult and complex, even apart from problems of estimating technical factors affecting costs and revenues.

In addition to the economic evaluation described above, which is designed to reflect the overall net "economic" return to the United States, the Finance Study Group also conducted payout analyses of the canal options. These analyses illustrate that it would be possible to create a financially viable canal operating agency even though for the Federal Government, as a whole, the project may not be economically feasible in terms of the benefits and costs evaluated in this Study.

The payout analyses are conducted so that the implications for tolls can be evaluated depending on the portion of the investment determined to be reimbursable, the rate of interest, and other costs to be charged to the agency. Such determinations may be appropriate to the extent of the foreign policy, defense, and other non-revenue benefits attributable to the investment in new facilities which are not considered in the economic evaluation. In the case of the present Panama Canal Company, for example, the nominal Federal capital on which interest is paid is less than half the unamortized capital investment in the lock canal and associated facilities, the rate of return paid on the nominal capital is far below current market yields, and the bulk of the present annual payment to Panama is not charged against canal revenues.

Period of Analysis

A 60-year period of operation of the new facilities is examined in both the economic evaluation and the payout analysis. Each investment option is examined for assumed opening dates for the new facilities ranging from 1990 to 2020. With construction periods ranging from 10 to 16 years, the analyses, therefore, treat new construction beginning from

1974 to 2010. The analyses also assume that the existing lock canal facilities will remain under U.S. control throughout the period under examination.

Risk and Uncertainty

Risk and uncertainty are involved in any investment project; the outcome may be better or worse than assumed in the planning. The most appropriate method for dealing with these factors is to make explicit allowances in the estimations of revenues and costs and to compute expected values and probability distributions. An alternative is to provide an allowance against adverse results by using a higher discount rate for project evaluation.

Office of Management and Budget Circular No. A-94 requires explicit consideration of risks, which has been done on the revenue side in the interoceanic canal studies through adoption of two "equally likely" estimates of future tonnage through an enlarged canal facility. The "potential" and "low" tonnage projections in the Shipping Study Group Report are intended to provide a basis for an estimate of the range of possible revenues. Estimated revenues are a function of the tonnage estimate and the toll rates applicable to the tonnage. However, the level and structure of toll rates, the composition of traffic, and the volume of traffic transiting the canal are interrelated. The Commission accepted the fact that the Shipping Study Group was unable to forecast the details of canal traffic so far into the future, and considered it impractical and undesirable to attempt to prescribe the level and structure of future toll rates. Therefore, a basic uncertainty must necessarily prevail with respect to the revenue estimates.

On the cost side, there is historical evidence of construction cost overruns in various civil works projects. However, faulty estimates, as such, have accounted for a very minor portion of increased project costs. In any event, the construction cost estimates for the canal options include contingency allowances averaging 12 percent, which do not appear unreasonable based on past experience.

Inflation

In both analyses cost and revenue data are in current prices. These are maintained throughout the period of analysis with no adjustments made for possible changes in price levels. In this sense, the current price relationships are assumed to remain stable over time. The Shipping Study concluded that canal tolls could be increased by the amount of inflation in competing transportation modes without diverting traffic from the canal. However, toll rates for the existing Canal have not been changed materially since the Canal was opened, even though the general level of prices and costs has increased substantially. In addition, the Shipping Study conclusion may need some modification if there are differential rates of inflation in the cost of competing transportation services.

Inflation could be a significant factor as far as construction costs are concerned. Approximately 70 percent of the estimated costs involve earth excavation which historically has experienced only a moderate rise in cost owing to constantly improving technology. In recent years, however, excavation costs have begun to rise at a rate approaching that of the entire construction industry.

Royalties

Host country payments are not included in the economic evaluation since the question of the distribution of benefits is logically separable from the question of the measurement of total benefits. They are included in the payout analyses as part of the bookkeeping. The Panama Canal Company, however, is not now charged with the bulk of present payments to Panama.

Future Finance of the Present Panama Canal

Continued operation of the present Panama Canal provides a benchmark against which the financial performance of other canal options may be measured. The present canal is not comparable in terms of maximum ship sizes which could be accommodated by the contemplated sea-level canal alternatives. The transit capacity of the present canal, even if improved as recommended in the Kearney Report, would be 26,800 transits a year, and this traffic level is projected to be reached at various dates from 1989 on. After the present canal is saturated, it would not be comparable to the sea-level canal options in transit capacity.

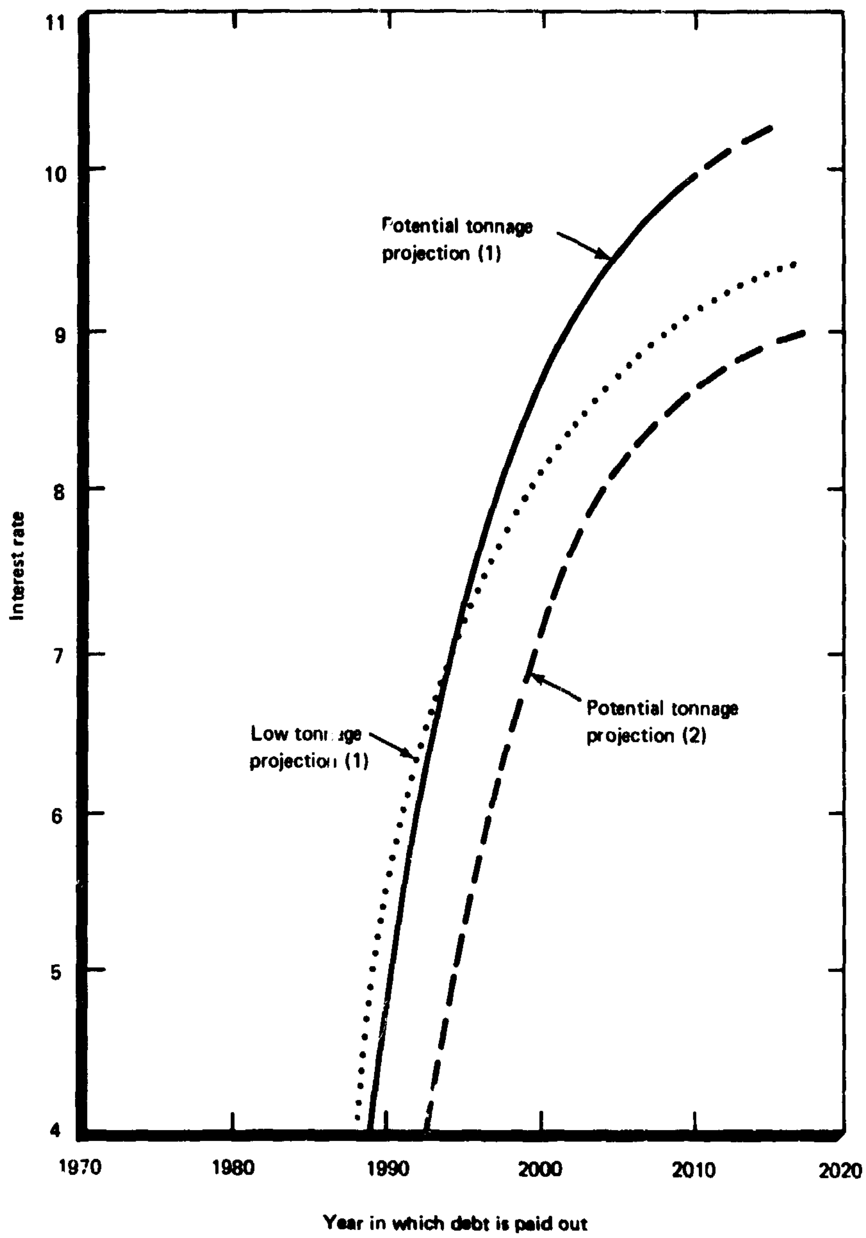
The analysis of continued operation of the present canal assumes continuation of Canal Zone Government costs, improvement of the canal as recommended in the Kearney Report, liquidation of the cost of this improvement as well as the present debt on which the Panama Canal Company pays interest to the United States Treasury, and payment of royalties to Panama. Projected revenues from the present canal would be sufficient to retire the current debt and amortize the Kearney improvements at interest rates ranging up to about 10 percent, as shown in Figures III-1 and III-2. On the basis of the unamortized capital investment in the present canal – approximately $700 million – rather than the interest-bearing debt, the rate of return would be reduced to from 6 percent to 7 percent, somewhat less than the current borrowing costs of the Federal Government but within the recent range of these costs. Continued operation of the canal to 2050, assuming this to be possible without replacing the locks, would build up substantial reserves.

Analytical Factors

Toll Rate and Structure

There would be major differences between a sea-level canal and the existing canal in the capability to handle sizes and numbers of ships. To determine the economic advantage to be gained by providing the additional capacity of a sea-level canal it is desirable to compare the maximum realizable net revenues from a sea-level canal and from the existing lock canal. This analytical procedure should not be interpreted as advocating an increase in tolls to maximum levels: pricing policy is complicated and related to aims other than purely commercial revenues. Nevertheless, estimating the maximum realizable net revenues from a sea level canal and from the existing lock canal would be useful for evaluating the cost of achieving additional capacity because the difference would be the amount of net revenue that marginally could be attributed to the investment in a sea-level canal.

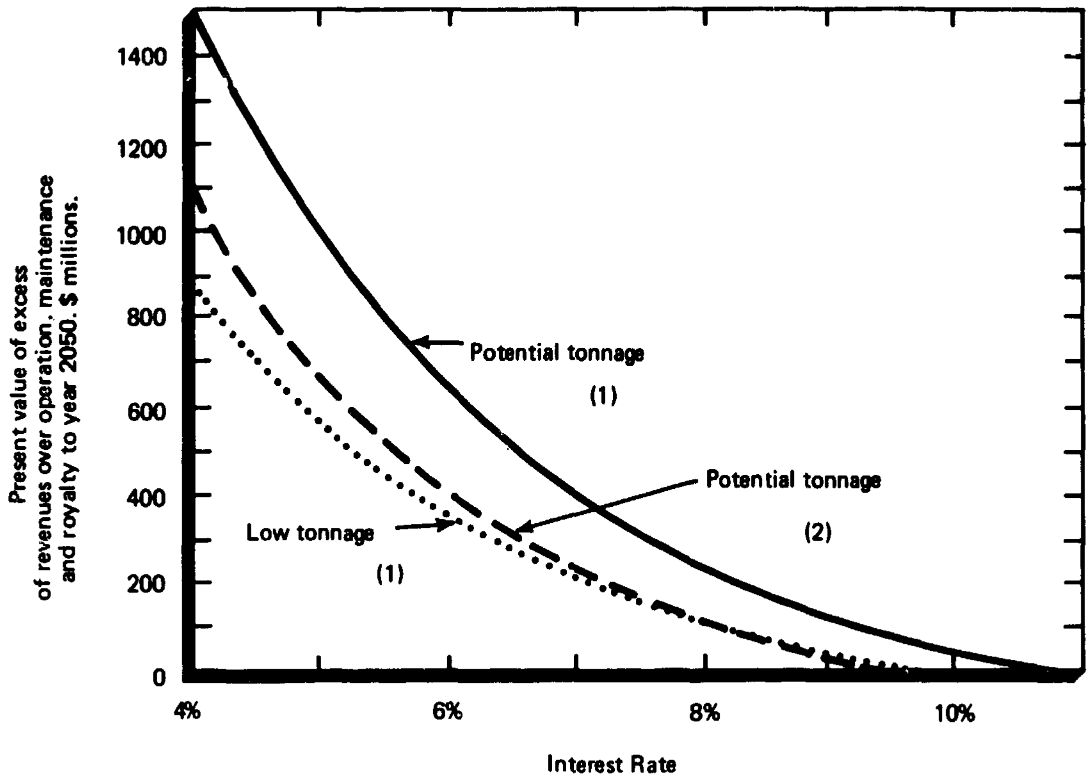
The Shipping Study estimated the demand for transisthmian crossings in cargo tons and associated transits–the "potential" and "low" tonnage forecasts–and the potential supply of such crossings in cargo tonnage capacity and related transits of the existing lock canal.



NOTES:

1. Toll rate assumed as $0.884 per cargo ton.
2. Tolls based on existing Panama Canal structure and rates.
3. 1970 Panama Canal debt assumed as $317 million.
4. $92 million canal improvement program assumed.
5. Royalties reach $0.22 in 1976.

PANAMA CANAL
ESTIMATED PAYOUT DATE OF DEBT VS. INTEREST RATE
FIGURE III-1



NOTES:
1. Tolls assumed as $0.884 per cargo ton.
2. Tolls based on existing Panama Canal System.
3. 1970 PCC debt of $317 million and $92 million improvement costs assumed paid out first.
4. Royalties reach $0.22 per cargo ton in 1976.
5. Neither deep draft locks nor replacement locks assumed to be constructed.

CONTINUED OPERATION OF PRESENT PANAMA CANAL

FIGURE III-2

The excess of the tonnage demand forecast over the capacity of the existing lock canal, therefore, is an estimate of the demand for additional transisthmian facilities. Without allowing for the effects of a change in tolls or toll structure on total demand, the product of estimated excess tonnage demand and various toll rates is a measure of the revenue which could marginally be attributed to the investment in additional canal facilities.

From an economic viewpoint, the demand for canal services is a function of the price charged for those services. Tolls for use of the existing canal have not been materially changed since the canal was opened, so that, as a result of inflation in world prices, real tolls have actually declined. It may be suggested that adjustments in toll rates may provide a means for assuring the most economical use of canal facilities.

The Shipping Study points out that the cost of alternative means of placing a commodity in the hands of the final buyer provides an upper limit on tolls that could be charged for use of the canal. In many cases, the most likely alternative to shipments through a transisthmian canal would be the use of larger ships which can economically use other routes. In fact, the trend toward the development and use of supership bulkers and tankers is well established. This trend can be interpreted as suggesting a decline in the economic value of a transisthmian canal as a result of advances in technology. In this connection, at toll levels lower than the existing Panama Canal tolls the Shipping Study indicates that a canal that could transit ships of 200,000 and 250,000 DWT could compete with alternative routing for larger ships.

Focusing only on revenue producing benefits and dollar cost outlays, the approach prescribed for evaluating Federal public works projects[2] would require that the revenue projections for each of the canal options be based on a toll structure and related charges which would maximize the net benefits from canal operations. It should be emphasized, however, that this analytical requirement would not prejudice decisions bearing on the distribution of potential financial and economic benefits among the United States, the host country, and third countries. However, it can greatly facilitate weighing the relative costs and benefits of the alternatives open to the United States, focus attention on the merits of the policy of subsidizing canal traffic, and assist in reconciling policies concerning the canal with other Federal policies.

Scale of Development

From an economic viewpoint the objective of any undertaking is to maximize the net present value—excess of benefits over burdens on a present value basis—of an investment. For comparisons of the relative economic efficiency of two equal investments the ratio of benefits to burdens, both in terms of present value, should be used. Net present value is maximized when a development is extended to the point at which the benefits added by the last increment of scale are equal to the burdens involved in adding that increment of scale. This maximizing approach is recognized and prescribed for project planning and formulation for Federal water resources projects by Executive Branch agencies.[3] In the economic

[2] Ibid.

[3] Ibid.

evaluation of the canal options in this Study, benefits equate to revenues and burdens to construction, operating and other identifiable costs.

From an economic viewpoint the sea-level and other canal investment alternatives constitute an incremental addition to the existing transisthmian facilities. From this viewpoint, therefore, only those revenues associated with the additional traffic exceeding the capacity of the existing canal are relevant for evaluating an investment decision. Figures III-3 and III-4 illustrate the tonnage demands estimated by the Shipping Study Group (the "potential" and "low" projections, respectively), the estimated capacity of the present Panama Canal, and the demand in excess of the capacity of the present canal. The product of this excess demand and various toll rates provides the incremental revenues used in the economic evaluation.

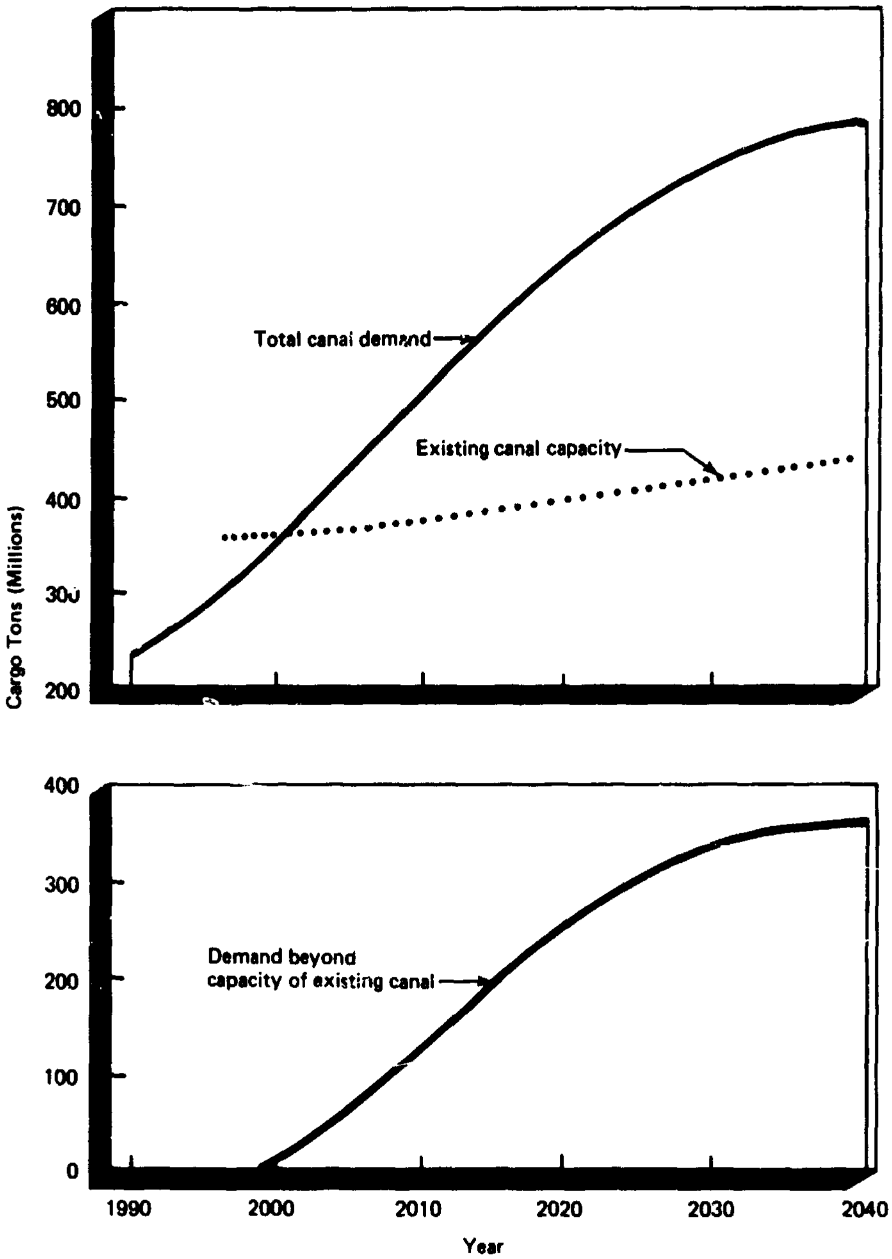
To maximize the net present value of any new canal investment, the project should be extended to the point at which the present value of the incremental revenues just equals the present value cost of providing the incremental capacity. In this connection, the Shipping and Engineering Studies suggest that there may be an engineering scale problem. The capacity of the existing lock canal is limited in both the number of annual transits and the maximum ship size which can be accommodated. The present canal, improved as recommended in the Kearney Report, would provide capacity for 26,800 annual transits. A sea-level canal on Route 10 would provide capacity for 38,000 annual transits–an incremental capacity of 11,200 transits–under currently known safe ship operating methods in restricted channels. In terms of maximum ship size, the present canal with its maximum ship capacity of 65,000 DWT is of sufficient dimensions to accommodate about 90 percent of the ships in the world fleet in the year 2000 and about 80 percent in the year 2040. A sea-level canal on Route 10 would be able to accommodate ships up to 150,000 DWT under all conditions and ships of 250,000 DWT under favorable conditions. The Shipping Study indicates that the added costs of providing channels large enough to handle superships might not be recoverable from tolls on such ships in view of the economical alternative routes available to these ships.

The requirement to relate the incremental costs of the canal options–to include varying channel sizes–and the incremental projected revenues to be realized from each option was recognized at an early date in the sea-level canal investigation. However, because of the uncertainties inherent in the very long range forecast of the Shipping Study and the aggregative forecasting methodology employed, this analysis was not carried forward.

Discount Rates

The purpose of discounting is to provide a common basis for comparing alternative uses of resources where the time patterns of benefits and costs are different and one alternative is not clearly superior in every respect to all other uses of resources. Assuming two alternatives involving the same capital investment are technically feasible, that with the larger present value is clearly relatively more desirable from an economic viewpoint. Since relative evaluations may be changed by the use of one discount rate rather than another, however, the choice of a proper discount rate is extremely important.

In addition to its use in comparing time streams of costs and benefits, a discount rate is also needed to compare financial flows. For this purpose, if an agency is to be able to meet

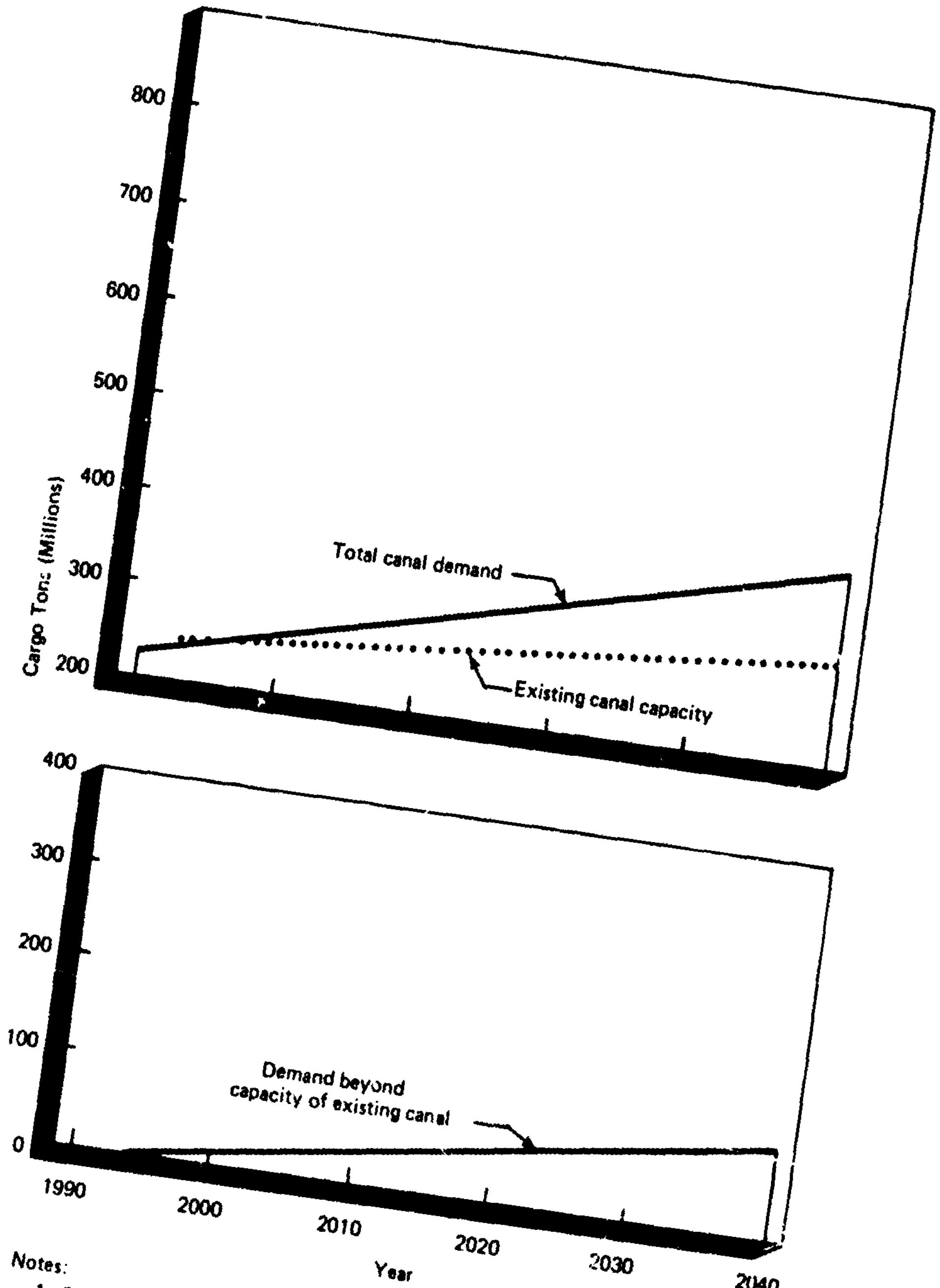


Notes:

1. Canal demand is potential tonnage forecast.
2. Existing canal capacity based on 25% freighter cargo mix, 65,000 DWT maximum ship size, and 26,800 annual transits.

CANAL DEMAND AND EXISTING CAPACITY
POTENTIAL TONNAGE PROJECTION

FIGURE III-3



Notes:

1. Canal demand is low tonnage forecast.
2. Existing canal capacity based on 46% freighter cargo mix, 65,000 DWT maximum ship size, and 26,800 annual transits.

CANAL DEMAND AND EXISTING CAPACITY
LOW TONNAGE PROJECTION

FIGURE III-4

its debt service charges, the appropriate discount rate is at least as high as—and possibly higher than to provide a margin against uncertainties—the agency's cost of reimbursable capital. For a Federal investment, therefore, an appropriate discount rate should be at least the current cost of money to the United States, i.e., current market yields on outstanding Treasury obligations with maturities comparable to the period of investment.

While the Treasury does not enter the market to borrow a specific amount for a specific period to finance an investment of an equal amount for the same period, it is, in general, compelled to have a comparably greater amount of debt outstanding over the period, and the most appropriate estimate of the cost to the Government would appear to be the current market cost of borrowing for comparable maturities. The market yield formula, moreover, provides a current measure of the minimum cost of money in the economy, since Treasury borrowing costs are lower than private borrowing costs, and thus serves as a minimum measure of the opportunity cost of public or private investment.

Any Government project uses economic resources. In the absence of Government investment, these resources would be available to the private sector. The opportunity to consume or invest and earn a rate of return for a different use by the private sector is foregone as a result of the Government investment and constitutes the opportunity cost of the Government investment. Thus, use of a discount rate lower than the opportunity cost of capital in the private sector can lead to a misallocation of resources from the private sector to the public sector and from a higher return use to a lower return use within the public sector.

For these reasons, the Subcommittee on Economy in Government of the Joint Economic Committee concluded that the optimum allocation of resources requires the use of economically relevant discount rates in the evaluation of public investments and proposed the opportunity cost of displaced private spending as a correct conceptual basis for the Government discount rate.[4] Office of Management and Budget Circular No. A-94 prescribes use of a discount rate related to current yields on Government securities and a higher rate reflecting opportunities foregone in the private sector for evaluation of all projects with costs or benefits extending over three or more years.

Some analysts believe that the principle that the discount rate used to evaluate Government projects should reflect opportunities foregone across the private economy as a whole must be modified for the analysis of Government projects which would displace private investments. In the latter case, these analysts suggest that the appropriate discount rate is the private rate of return on investment in the particular industry affected. Even with this qualification, however, most analysts would agree that the private rate of return on an equity investment must be at least approximately twice the current market yield on outstanding Treasury securities, since, in order to attract equity capital from private investors, the industry must be able, after payment of the corporate income tax, to offer investors a return not less than the return obtainable without risk on Treasury secuities.[5]

[4] "The Planning-Programming-Budgeting System: Progress and Potentials", December 1967; and "Economic Analysis of Public Investment Decisions: Interest Rate Policy and Discounting Analysis", 1968.

[5] See, for example, William J. Baumol, "On the Discount Rate for Public Projects", in Joint Economic Committee, *The Analysis and Evaluation of Public Expenditures: The PPB System*, A Compendium of Papers Submitted to the Subcommittee on Economy in Government (91st Congress, 1st Session).

Since the Federal Government would assume some equity type risks in supporting directly or indirectly an investment in new canal facilities, the expected overall rate of return on the investment should be sufficiently above the cost of Treasury financing to afford equitable compensation for the assumption of that risk. Consequently, in the economic evaluation the Finance Study Group has analyzed the various canal options at discount rates of 6, 9, and 12 percent. Rates in the lower end of this range are in the area of market yields on U.S. Government securities in recent years. Rates in the upper end of the range would more nearly reflect the opportunity cost of capital in the private sector.

Economic Evaluation

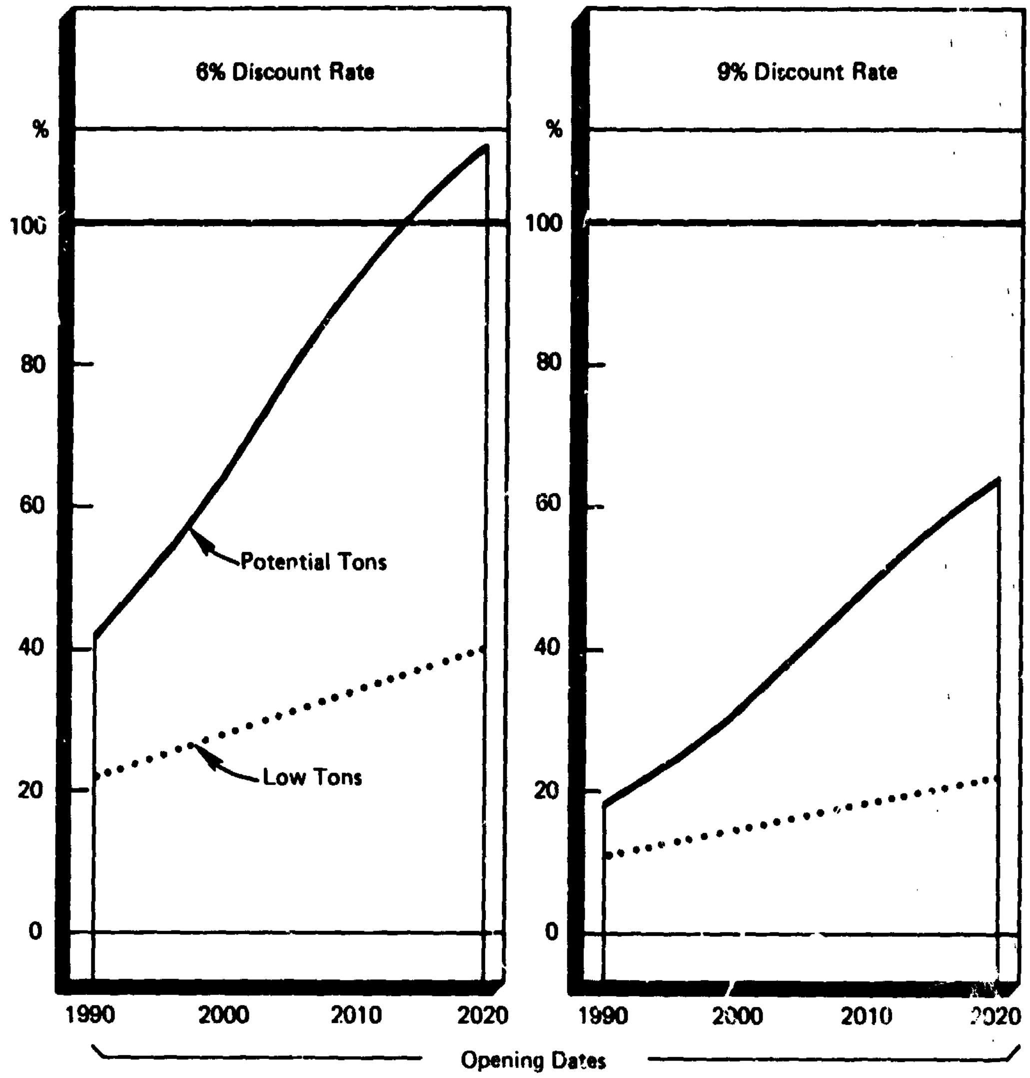
Based on incremental benefits (revenues), neither the Route 10 nor Route 14S sea-level canal alternatives, nor the addition of a third lane of locks to the existing lock canal, Route 15, is commercially feasible if identified benefits are required to cover the whole of investment and operating costs, unless construction is substantially delayed and financing costs are below current Treasury financing costs. If a sufficient part of the investment cost is chargeable against foreign policy, defense, and other noncommercial benefits, however, construction and operation of a sea-level canal may still be in the national interest.

Conversely, the present value of the deficit resulting from the economic evaluation provides a measure of the cost to the Nation of obtaining the foreign policy, defense, and other benefits that may be attributed to the project.

Route 10

Computations summarized in Figure III-5 indicate the fraction of construction costs that could be recovered through the additional revenues and cost savings attributable to a Route 10 canal. As indicated in Table III-1, the net present value cost of opening Route 10 in 1990 would be $720 million to $1 billion depending upon the interest rate used in the evaluation and upon whether the potential tonnage or low tonnage forecast were to materialize. The corresponding level annual revenue deficiency during each year of the 60 year period of operation would range from $150 million to $400 million.

The analyses summarized in Figure III-5 and Table III-1 assume that as experience with operating ships in restricted waterways is developed, the Route 10 channel would prove to be sufficient to accommodate the 39,300 annual transits which would be necesary in the year 2040 to carry the "potential" tonnage projection with the 25 percent freighter cargo ship mix. (The "low" tonnage projection would require 31,500 annual transits in the year 2040). If improved ship operation technology is not developed so that the maximum transit capacity of Route 10 is limited to 38,000 annual transits, a level which would be reached in the year 2025 with the "potential" tonnage/25 percent freighter cargo mix projection, the net revenues of the Route 10 option would be reduced (net deficit increased, net surplus reduced) by the amounts shown in Table III-2. Table III-2 also indicates that the increased net revenues attributable to the increased traffic which could be accommodated if a by-pass were constructed would not be sufficient to recover the construction cost of the by-pass project.



Source: Table III-1.

NET REVENUE AS PERCENTAGE OF CONSTRUCTION COST
Present Value Basis – Route 10

FIGURE III-5

TABLE III-1
ROUTE 10
Net Revenue as a Percentage of Construction Cost, and Net Worth by Opening Date. Present Value in 1970.
(Dollars in millions)

Opening Date and Discount Rate	Shipping Study Tonnage Forecast: Potential Tons — Revenue as % of Cost	Potential Tons — Net Worth	Potential Tons — Average Annual Deficiency	Low Tons — Revenue as % of Cost	Low Tons — Net Worth	Low Tons — Average Annual Deficiency
1990						
6%	40%	$-766	$152	21%	$-1,014	$201
9%	18	-721	366	11	- 782	397
2000						
6%	63%	$-266	$ 95	27%	$- 524	$186
9%	30	-[illegible]3	310	14	- 318	382
2010						
6%	91%	$- 36	$ 23	34%	$- 266	$159
9%	49	- 80	227	18	- 128	364
2020						
6%	111%	$ 24	$-27	40%	$- 134	$153
9%	63	- 25	168	22	- 51	343

Notes:

[1] Existing Panama Canal toll structure and rates.

[2] No royalty.

[3] Net revenue equals gross revenue attributable to tonnage in excess of the capacity of the existing canal plus operating cost savings resulting from closing the existing canal less cost of operating the Route 1[illegible] [illegible]nal.

[4] Average annual deficiency is the level annual revenue shortfall over the 60 year period of operation.

Route 14S

A Route 14S sea-level canal would involve a larger commercial deficit because of higher construction costs and a longer construction period. Thus, the cost on a present value basis of opening Route 14S in 1990 would range from about $960 million to $1.26 billion, depending on the interest rate and tonnage. The 60 year level annual revenue deficiency would be $200 million to $515 million. (See Figure III-6, and Table III-3).

No analysis of the effects of increased transiting capacity on Route 14S was undertaken because the minimum Route 14S capacity of 39,000 annual transits would be sufficient to accommodate the "potential" tonnage/25 percent freighter cargo mix until about the year

TABLE III-2
Route 10 — By-Pass Project
Net Revenues, and Net Revenues
as a Percentage of Construction Cost,
Present Value in 1970.
(Dollars in millions)

Opening Date and Discount Rate	Net Revenues	Net Revenues as % of Cost
1990		
6%	$6	30%
9%	1	19
2000		
6%	$7	37%
9%	1	21
2010		
6%	$8	40%
9%	1	23
2020		
6%	$8	43%
9%	1	23

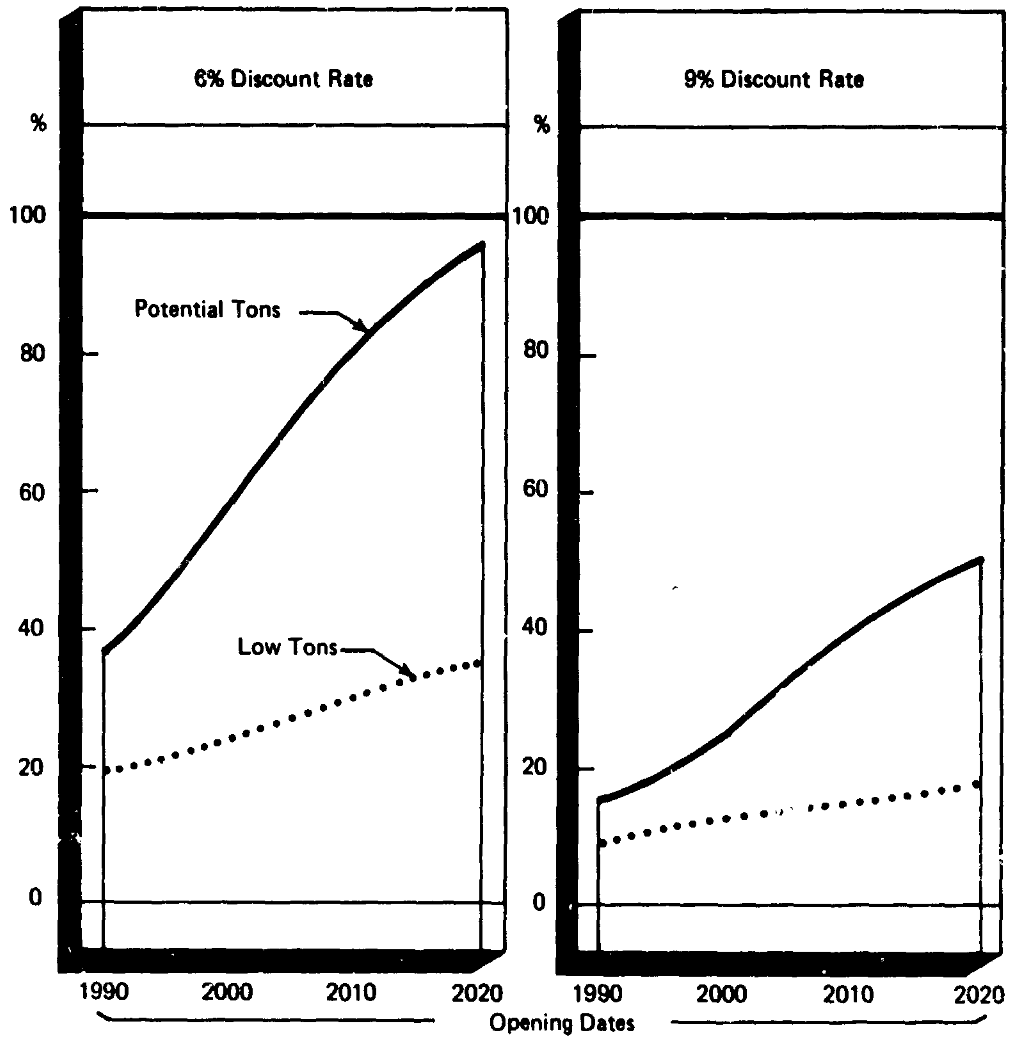
Notes:

[1]Opening date is date the Route 10 channel would be opened. The by-pass would be opened in each case in 2025. The 60 year analysis period begins with opening date of Route 10.
[2]Existing Panama Canal toll structure and rates.
[3]No royalty.
[4]Potential tonnage, 25 percent freighter cargo mix projection.

2035, and the incremental revenues to be gained from construction of increased transiting capacity would be lower than the incremental revenues attributable to a Route 10 by-pass.

Replacement of the Existing Lock Canal Facilities

The sea-level canal options have been examined on a comparative basis with continued operation of the existing lock canal. A consideration in the evaluation of alternatives is the possibility that the locks of the existing canal may require major replacements at some indeterminate time in the future. The foregoing analyses have not included provision for this contingency. If the existing lock canal should need major replacements during the period of



Source: Table III-3.

NET REVENUE AS PERCENTAGE OF CONSTRUCTION COST
Present Value Basis – Route 14S

FIGURE III-6

TABLE III-3
Route 14S
Net Revenue as a Percentage of Construction Cost, and Net Worth by Opening Date. Present Value in 1970. (Dollars in millions)

Opening Date and Discount Rate	Shipping Study Tonnage Forecast: Potential Tons			Shipping Study Tonnage Forecast: Low Tons		
	Revenue as % of Cost	Net Worth	Average Annual Deficiency	Revenue as % of Cost	Net Worth	Average Annual Deficiency
1990						
6%	34%	$-1,008	$200	18%	$-1,256	$249
9%	14	- 956	485	9	-1,016	515
2000						
6%	53%	$- 401	$142	23%	$- 659	$234
9%	24	- 357	429	11	- 417	501
2010						
6%	77%	$- 111	$ 71	28%	$- 341	$217
9%	39	- 122	347	14	- 170	483
2020						
6%	93%	$- 18	$ 21	34%	$- 177	$202
9%	50	- 42	283	18	- 69	464

Notes:

1. Existing Panama Canal toll structure and rates.
2. No royalty.
3. Net revenue equals gross revenue attributable to tonnage in excess of the capacity of the existing canal plus cost savings resulting from closing the existing canal less cost of operating the Route 14S canal.
4. Average annual deficiency is the level annual revenue shortfall over the 60 year period of operation.

analysis, the present value net worth of the existing canal (See Figure III-2) would be reduced by the present value of the replacement costs, and the present value net worth of the sea-level canal options (See Tables III-1 and III-3) would be correspondingly increased. As indicated in Chapter II, a cost of $800 million has been used for evaluation purposes.

Table III-4 contains the present values in 1970 of the replacement expenditures, assuming the replacement is begun in the year 2000, 2010, or 2020. The present value of the replacement cost represents the reduction in the net worth of the existing canal, if major replacement is proved to be necessary, and the corresponding increase in the present value

TABLE III-4
Cost of Replacement of Existing Lock Canal. Present Value in 1970. Millions of Dollars.

Year Replacement Begins	Discount Rate 6%	Discount Rate 9%
2000	114	45
2010	64	19
2020	36	8

net worth of the sea-level canal options. For example, if it is determined that the existing canal will require major replacement beginning in the year 2010, the net commercial deficit on a present value basis indicated in Tables III-1 and III-3 of the sea-level canal options would be reduced by $19 million if a 9 percent discount rate is used.

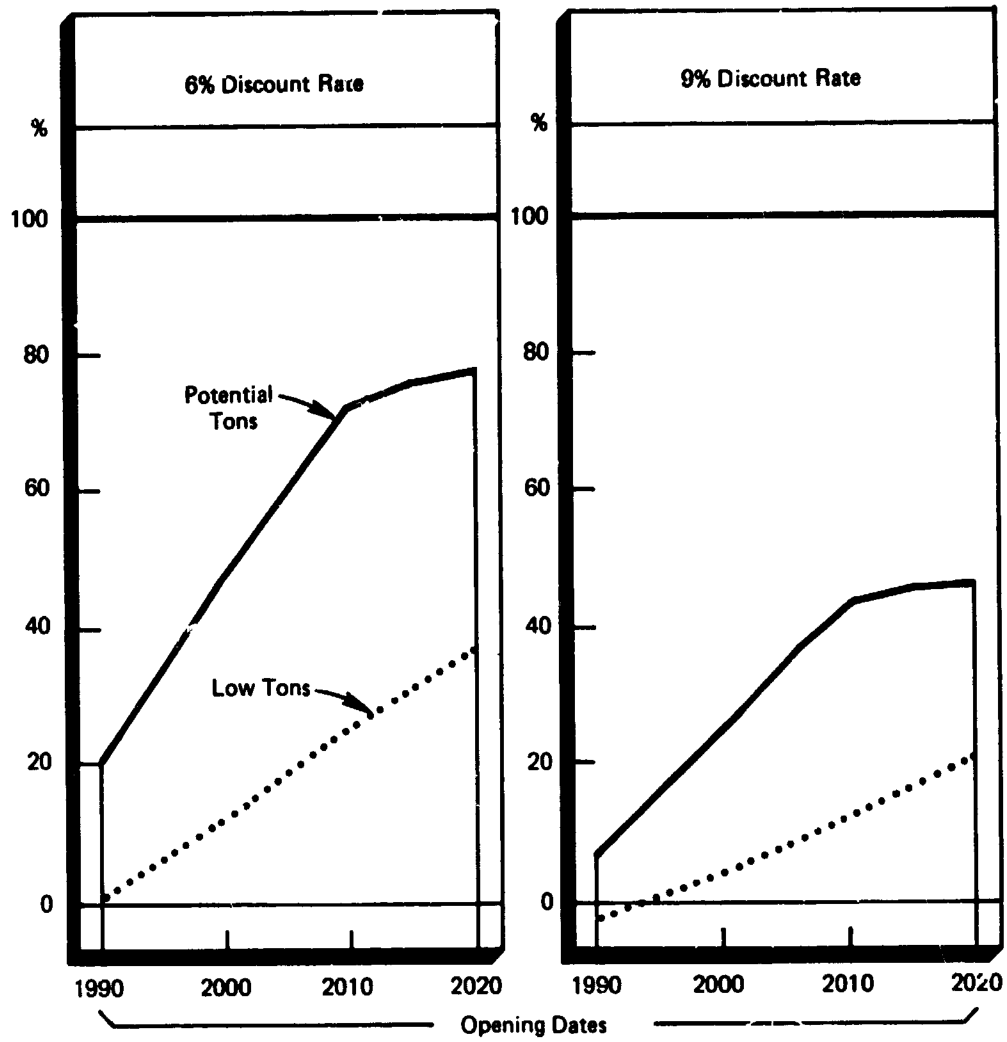
Route 15

The Route 15 option would require continued operation of the existing lock facilities; thus, there would be no operating cost savings. Taking into account the additional revenues from the added capacity provided, the cost on a present value basis of opening the third lane of locks in 1990 would range from about $370 million to $600 million, depending on the interest rate and tonnage. (See Figure III-7, and Table III-5). This option, like continued operation of the present canal, could involve a need to replace the existing lock canal facilities.

Payout Analysis

In addition to the foregoing economic evaluation, which reflects the overall net financial return to the United States, the Finance Study Group also conducted a series of payout analyses of the canal options. This approach is more restricted than the economic evaluation since it is directed to determining the circumstances under which revenues credited to an interoceanic canal operating agency would be sufficient to pay off costs charged to the agency. The payout analysis illustrates the balance between revenues and expenditures as it might appear on the books of an interoceanic canal operating agency over the period of analysis.

The basic feature of this "bookkeeping" approach is the dedication of all revenues from interoceanic canal transits to the payment of operation and maintenance costs, royalties, and the amortization of debt attributed to existing and new facilities. This differs from the previously described economic evaluation in which only incremental revenues were credited to each canal option. The primary objective of the payout analysis is to illustrate combinations of costs, interest rates, tolls, and royalty payments charged to the operating agency which would permit paying off the debt of the operating agency after the new canal has been in operation for 60 years. The variables considered included reimbursable



Source: Table III-5.

NET REVENUE AS PERCENTAGE OF CONSTRUCTION COST
Present Value Basis – Route 15

FIGURE III-7

TABLE III-5
ROUTE 15
Net Revenue as a Percentage of Construction Cost, and Net Worth by Opening Date. Present Value in 1970.
(Dollars in millions)

Opening Date and Discount Rate	Shipping Study Tonnage Forecast: Potential Tons: Revenue as % of Cost	Net Worth	Average Annual Deficiency	Low Tons: Revenue as % of Cost	Net Worth	Average Annual Deficiency
1990						
6%	20%	$-486	$ 96	1%	$-602	$119
9%	6	-372	189	-2	-403	204
2000						
6%	47%	$-179	$ 64	12%	$-299	$106
9%	24	-127	153	4	-160	192
2010						
6%	72%	$- 53	$ 34	25%	$-143	$ 91
9%	43	- 40	114	12	- 62	176
2020						
6%	77%	$- 25	$ 28	37%	$- 67	$ 76
9%	46	- 16	108	20	- 24	162

Notes:

[1] Existing Panama Canal toll structure and rates.
[2] No royalty.
[3] Net revenue equals gross revenue attributable to tonnage in excess of the capacity of the existing canal less the cost of operating the third lane of locks on Route 15.
[4] No provision for possible replacement of existing locks.
[5] Average annual deficiency is the level annual revenue shortfall over the 60 year period of operation.

construction costs, host-country payments, the "potential" and "low" tonnage projections, the date for opening a sea-level canal (between 1990 and 2010), and toll rates between $0.60 and $1.30 per cargo ton with adjustments at various dates. Unless otherwise specified, the toll rate associated with all analyses comprising the payout analysis assumes an average revenue of $0.884 per cargo ton regardless of cargo composition until the structure is changed to produce different levels of revenue.

Variations of the general method were used to explore the effect of the following factors on toll rates necessary to permit payout after 60 years of operation:

1. The various canal options under consideration.
2. Separation of the costs and revenues of the sea-le el canal options from those of the Panama Canal so that net revenues of the latter would not be available for defraying construction costs of a sea-level canal until the sea-level canal is placed in operation.
3. Combination of the costs and revenues of the canal options with those of the Panama Canal, making net revenues of the latter available for defraying construction costs.
4. Variation between the "potential" and the "low" tonnage projections of the Shipping Study.
5. Variation of the date when the canal option is placed in operation.
6. Variation of the date when the tolls are changed from the assumed rate of $0.884 per cargo ton to the rate required to liquidate all costs of both the old canal and the new option.
7. Variations in reimbursable cost.
8. Variations in the interest rate charged on reimbursable capital.
9. Variations in project transit capacity.

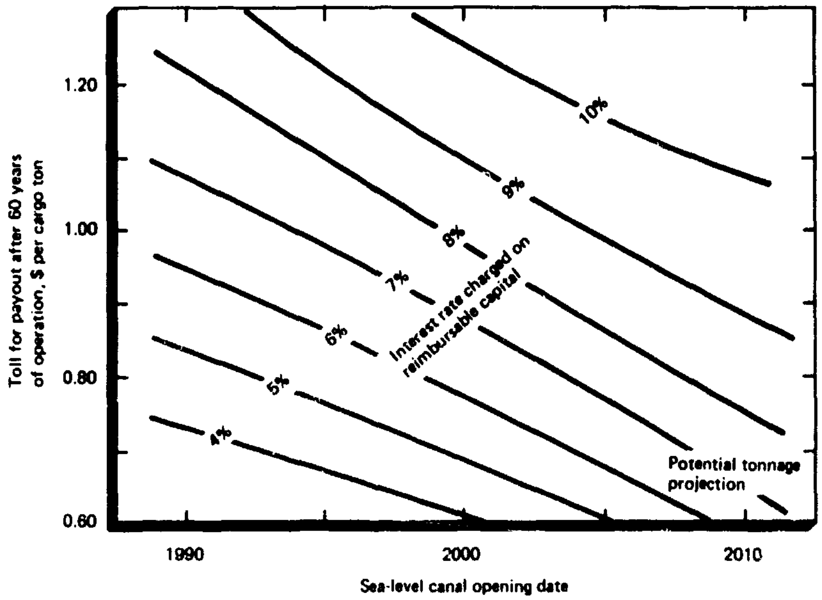
Detailed analyses for Routes 10, 14S, and 15 are contained in Appendix 1, Payout Analysis. The remainder of this Section discusses the payout analyses pertaining to Route 10, and concludes with a summary comparing the canal options under consideration in terms of toll rates which would be necessary in order for the books of the operating agency to show payout after 60 years of operation of the new facilities under certain assumptions as to costs and interest rates.

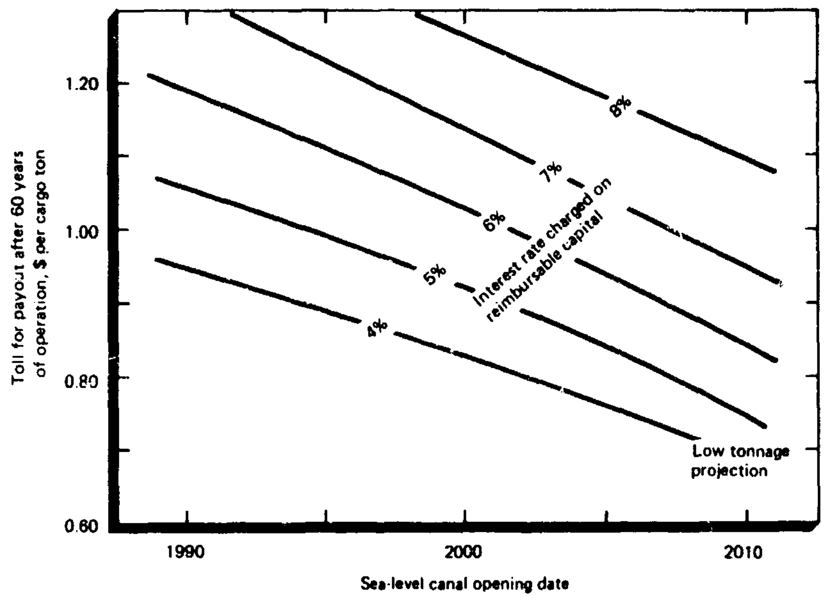
Route 10 – General

The financial circumstances most favorable for a sea-level canal on Route 10 have been taken as the lowest toll rate which would permit liquidation of all debts after 60 years of operation. These circumstances prevail when the costs and revenues of the existing canal are combined with the costs and revenues of the new canal to permit defraying new construction costs with net revenues from operation of the Panama Canal.

Generally, in order that Route 10 be self-liquidating after 60 years of operation, increases in toll level over that now prevailing at the Panama Canal would be required. If tolls are increased earlier rather than later, more revenue would be available for paying the debts incurred in constructing a new facility. Also, the earlier toll rates are increased, the smaller the required increase in tolls, or the higher the return that could be realized on the investment. Two dates for an increase in tolls have been examined, i.e., the date on which construction on Route 10 is started and the date on which the new facility is placed in operation. The earlier date is more favorable and is discussed further in this Chapter.

Net Panama Canal revenues available for paying for the construction of a new facility are dependent on the volume of traffic–the greater the volume, the greater the net revenue available. Since transisthmian canal traffic is projected to increase continuously, the later the new facility is constructed, the lower the required toll per cargo ton, or the greater the rate of return on the investment. Figure III-8 illustrates combinations of toll rates which would permit payout after 60 years of operation and opening dates for a sea-level canal on Route 10 at several interest rate levels, assuming toll rates are increased when construction is





NOTES:

1. Canal financing assumed an extension of that of the Panama Canal with a 1970 debt of $317 million.
2. Toll of $0.884 per cargo ton assumed until canal construction is started.
3. Panama Canal assumed on standby for ten years, and then in mothballs.
4. Route 10 cost is $2.88 billion.
5. Royalty reaches $0.22 in 1976.

ROUTE 10 TOLL PER CARGO TON VS. CANAL OPENING DATE

FIGURE III-8

started. Combinations for both the "potential" and the "low" tonnage projections are presented.

Cash Flows

Figures III-9 and III-10 illustrate the year-by-year changes in revenues, costs and debt which would prevail, and the toll rates which would be required to permit payout after 60 years of operation, if Route 10 were constructed under a particular set of assumptions. The assumptions and the reasons for selecting them are as follows:

1. Costs and revenues are combined with those of the Panama Canal to permit using net revenues of the latter to defray construction costs.
2. Toll rates are increased to $1.00 per cargo ton at the start of Route 10 construction to maximize net revenues which can be used to defray construction costs.
3. Sea-level canal commences operation in 2000 to permit use of the Panama Canal until its transit capacity is reached, and thus to maximize net revenues which can be used to defray construction costs.
4. Six percent interest is charged, somewhat below current Treasury borrowing costs but within the range of these costs in recent years.
5. Toll rates are changed after 10 years of operating experience (year 2010) to the rate necessary to achieve payout after 60 years of operation.

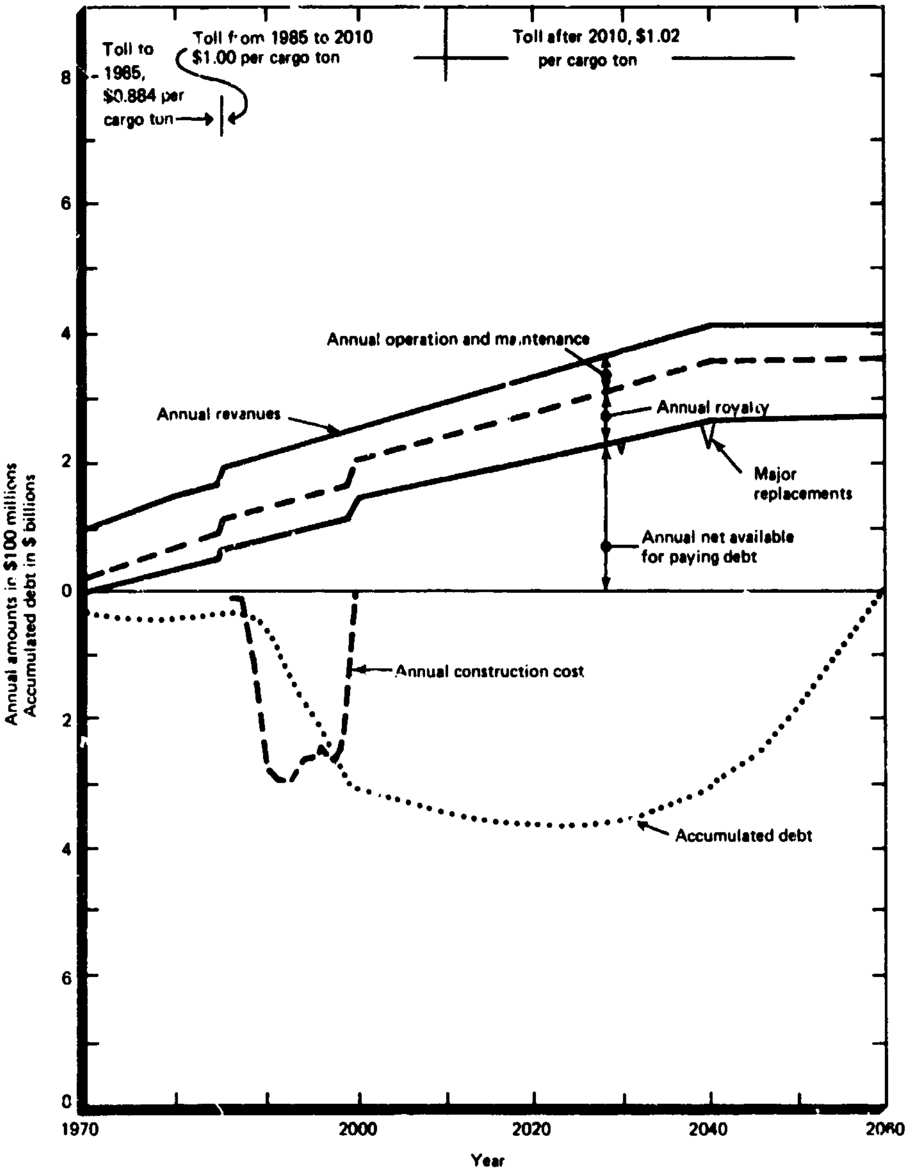
Figure III-9 shows that an average toll rate of $1.02 per cargo ton would be necessary for the period after 2010 to permit payout after 60 years of operation under the assumptions described above, if the low tonnage projection were to materialize. Figure III-9 also shows that the accumulated debt would continue to increase some 25 years after start of operation.

Figure III-10 shows what might happen under the same assumptions, but with the "potential" tonnage projection. The figure illustrates that toll rates could be reduced to $0.43 per cargo ton for the period after 2010 and still achieve payout after 60 years of operation. The figure also shows that liquidation of debts would begin immediately upon completion of the sea-level canal. Figure III-11 illustrates the implications for self-liquidating tolls if early completion (1990) of the sea-level canal were deemed necessary. The figure shows that a toll rate of $0.96 per cargo ton would be required from the start of construction throughout the period of operation to permit payout 60 years after opening even if the "potential" tonnage projection materialized. The figure also shows that the canal debt would continue to increase for some 30 years after start of operation, to a peak more than $2 billion greater than the debt when the canal opened.

Sensitivity of Self-liquidating Tolls to Reimbursable Costs

The costs which must be reimbursed from toll revenues might vary from the $2.88 billion presently estimated construction cost of a sea-level canal on Route 10 for a number of reasons. These include the following:

1. The cost of the canal might change during the design stage because of the additional foundation information which would become available from design stage explorations.

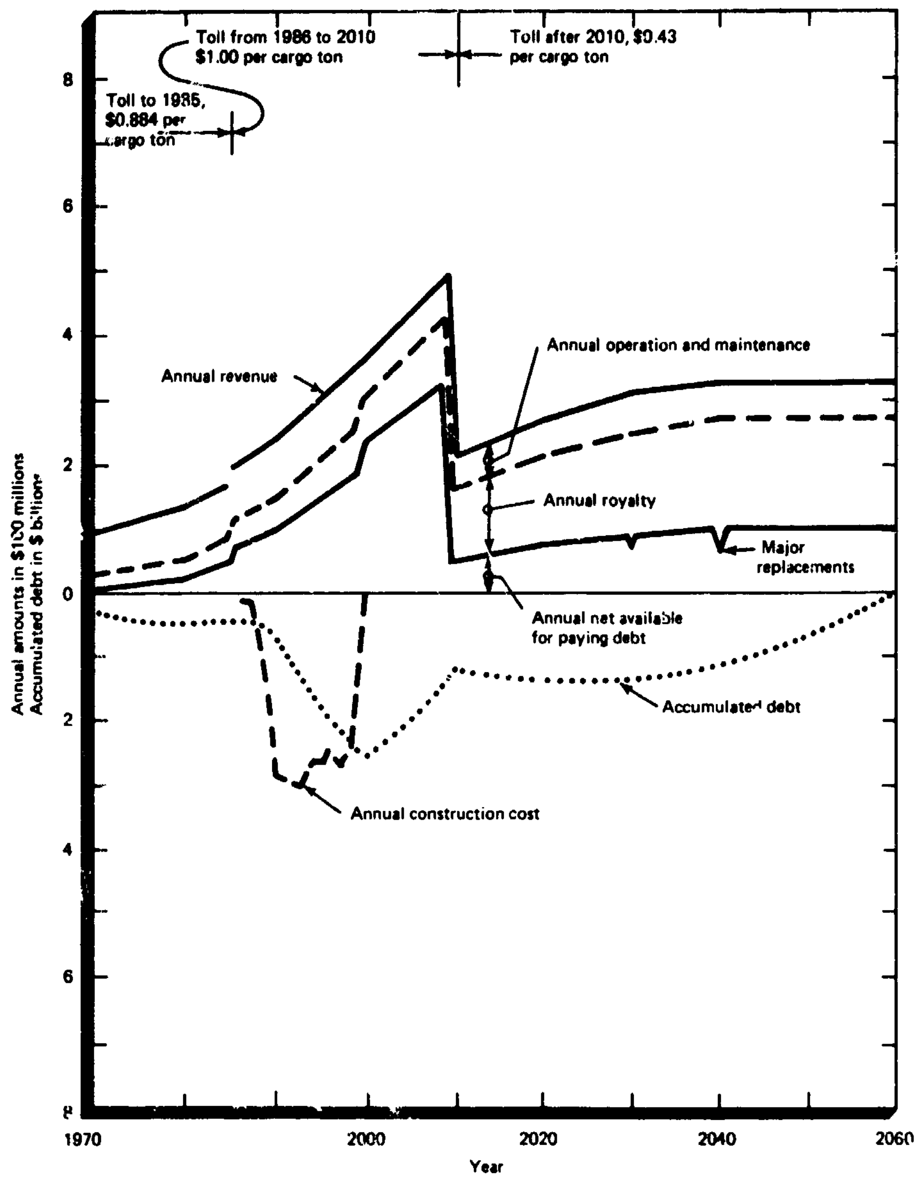


NOTES:

1. Construction cost is $2.88 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. New canal opens in 2000 for payout in 2060.
5. Low tonnage projection and 46% mix used.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Panama Canal kept on a standby for ten years and then in mothballs.

ROUTE 10 CASH FLOW ANALYSIS
(Low Tonnage, 46% Mix)

FIGURE III-9

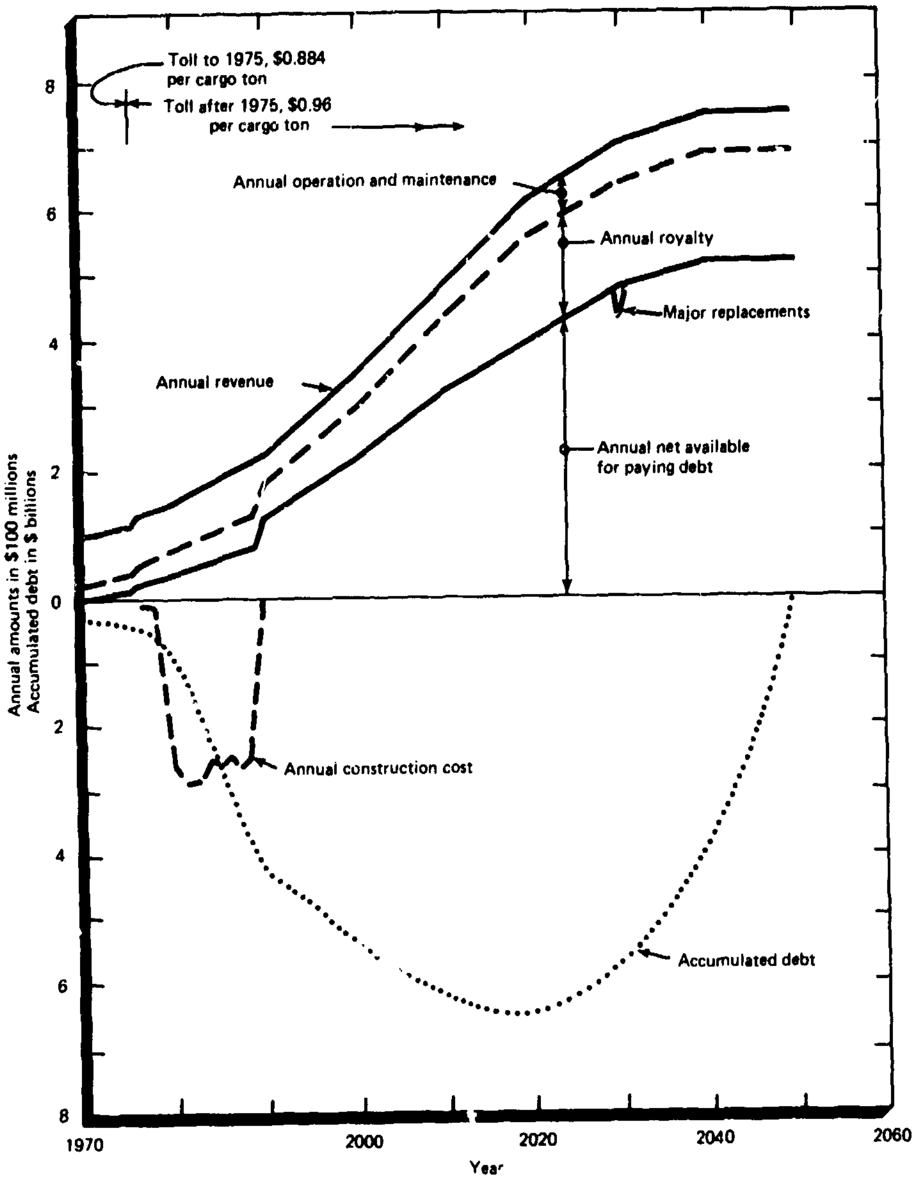


NOTES:

1. Construction cost is $2.88 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. New canal opens in 2000 for payout in 2060.
5. Potential tonnage projection and 25% mix used.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $3?7 million.
7. Panama Canal kept on standby for ten years, and then in mothballs.

ROUTE 10 CASH FLOW ANALYSIS
(Potential Tonnage, 25% Mix)

FIGURE III-10



NOTES:

1. Construction cost $2.88 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. New canal opens in 1990 for payout in 2050.
5. Potential tonnage projection and 25% mix used.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Panama Canal kept on standby for ten years and then in mothballs.

ROUTE 10 CASH FLOW ANALYSIS
(Potential Tonnage, 25% Mix)

FIGURE III-11

2. Part of the construction cost might be charged against presently unevaluated benefits, thus reducing the amount to be reimbursed from tolls revenues.
3. Part of the construction cost might be determined to constitute a subsidy, reducing the cost to be reimbursed from tolls revenues.
4. The channel size might be changed.
5. Treatment of present Canal investment might be altered.

An analysis was undertaken to determine the effect of variations in reimbursable costs on toll rates necessary to achieve payout after 60 years of operation at several interest rate levels. The results of the analysis are shown in Figure III-12. The computations are based on the "low" tonnage projection and the assumption that the sea-level canal would be opened for traffic in 2000.

Figure III-12 can be used in the following manner. Route 10, completed in 2000 at a cost of $2.88 billion, would be self-liquidating after 60 years of operation at 6% interest rate if a toll rate of $1.02 per cargo ton were charged from the beginning of construction and maintained over the 60 year period of operation. (The line identified as 6% passes through $2.88 billion as measured on the horizontal scale at a toll rate of $1.02 per cargo ton, as measured on the vertical scale.) If reimbursable costs were determined to be one-half billion dollars less for some reason, the corresponding toll rate would be $0.95 per cargo ton. (The line identified as 6% passes through $2.38 billion as measured on the horizontal scale at a toll rate of $0.95 per cargo ton, as measured on the vertical scale.)

Figure III-12 may also be used to approximate the effect of royalty rates differing from the $0.22 per cargo ton used in the analyses. For example, tolls of $0.83 per cargo ton, out of which royalties of $0.17 per cargo ton are paid, would have the same financial effect as tolls of $0.88 per cargo ton as read on the figure from which royalties of $0.22 per cargo ton are assumed to be paid.

Figure III-13 furnishes similar information for the "potential" tonnage projection.

Recoverable Construction Costs, Route 10, at Panama Canal Toll Levels

Payout analyses can be used to determine the approximate portion of Route 10 construction costs which could be recovered at various interest rates and toll levels. The amounts which could be recovered using current Panama Canal toll rates are examined below on the basis that the current tolls have not been changed materially since the Canal was opened, and may also be resistant to future change. The values in Table III-6 are taken from Figures III-12 and III-13.

Sensitivity of Tolls to Transit Capacity, Route 10

The Engineering Feasibility Study indicates that the capacity of Route 10 is 38,000 transits a year unless operational methods not now considered safe can be adopted after experience has been gained in operating the sea-level canal. The 38,000 transit capacity would be exceeded in about year 2025 if the "potential" tonnage forecast and 25% freighter cargo mix were realized. The effect on self-liquidating tolls is shown in Table III-7 for various assumed peak transit capacities for Route 10.

TABLE III-6
ROUTE 10
Recoverable Construction Costs at Current Panama Canal Toll Rates (Dollars in Billions)

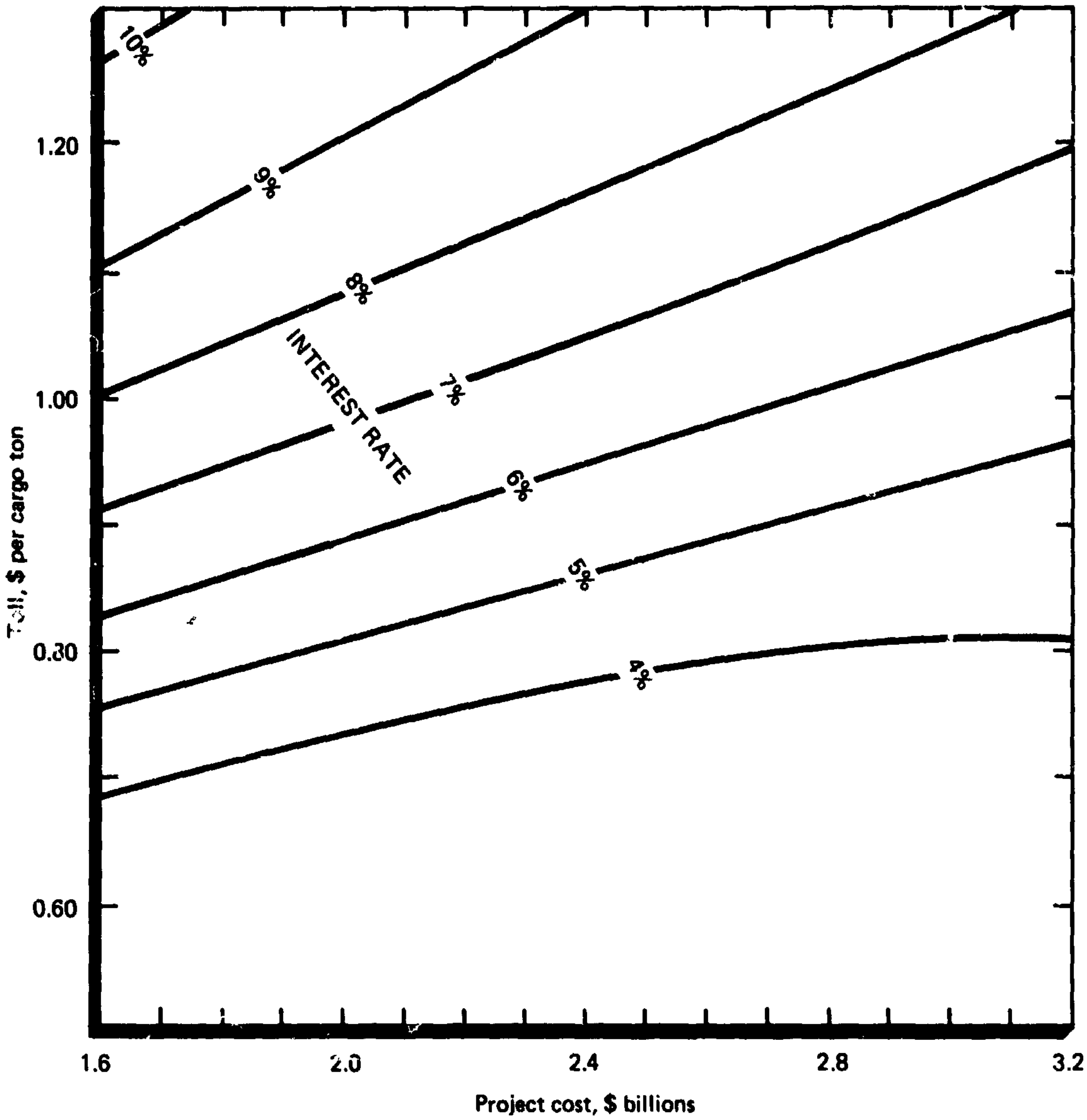
Interest Rate	Construction Cost Recoverable	Construction Cost Unrecoverable
"Potential" tonnage projection[1]		
6%	$2.9	$0.0
7%	2.1	0.8
7.6%	1.6[2]	1.3
"Low" tonnage projection[3]		
6%	2.0	0.9
6.7%	1.6[2]	1.3

[1] Based on a toll rate of $0.777 per cargo ton on the vertical scale of Figure III-13; corresponds to the 25% freighter cargo mix.
[2] Lower limit of reimbursable costs examined in the sensitivity studies.
[3] Based on a toll rate of $0.884 per cargo ton on the vertical scale of Figure III-12; corresponds to the 46% freighter cargo mix.

Table III-7
Self-liquidating Tolls for Route 10 as Affected by Transit Capacity

Capacity, transits per year	Self-liquidating toll per cargo ton [1]
39,300 and above	$0.957
38,000	0.960
36,000	0.966
34,000	0.974

[1] Construction started in 1975, operation in 1990; potential tonnage; royalties $0.22 per cargo ton; 6% interest rate; financing an extension of Panama Canal financing; toll of $0.884 until 1975; project cost $2.88 billion.

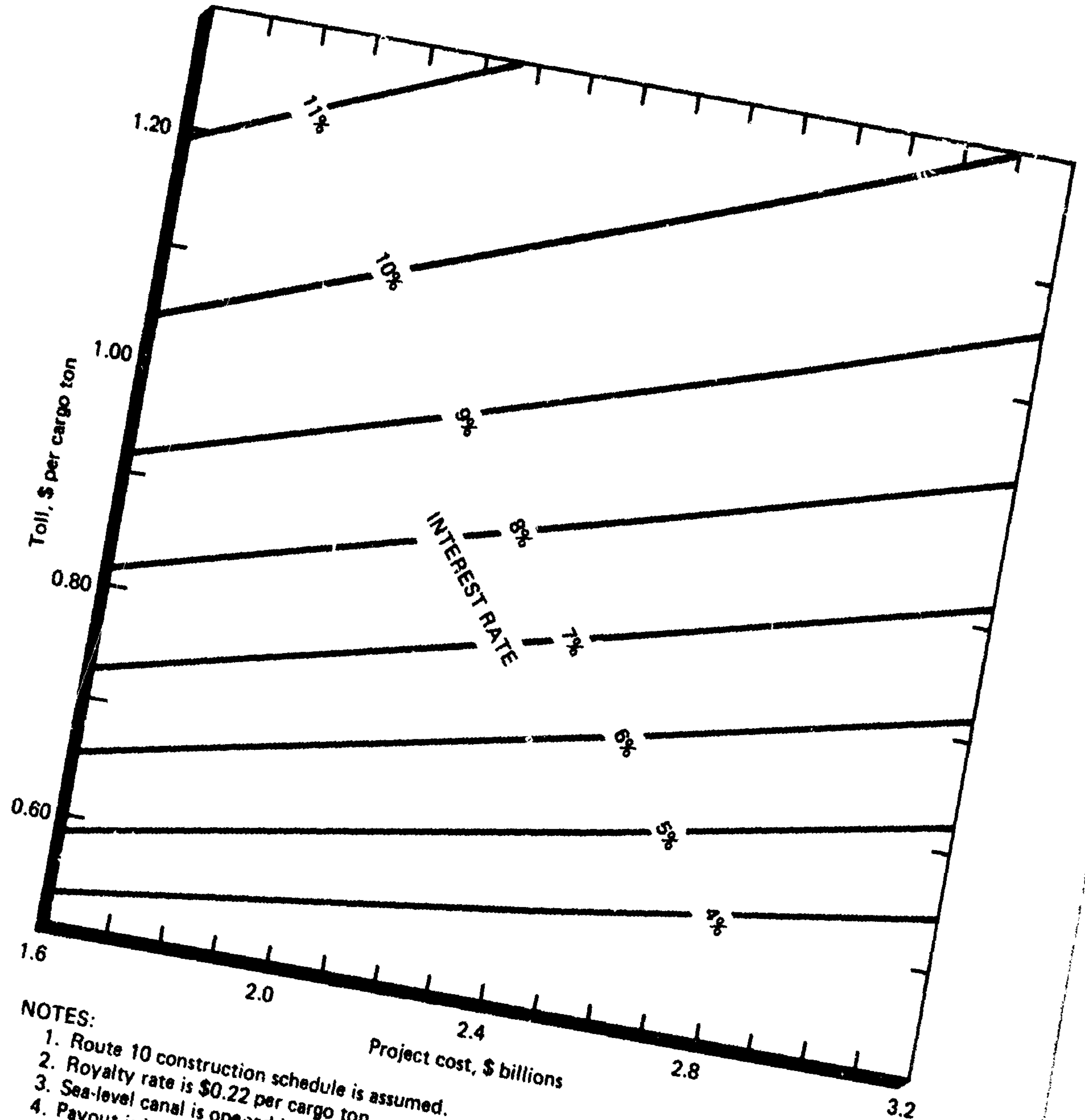


NOTES:

1. Route 10 construction schedule is assumed.
2. Royalty rate is $0.22 per cargo ton.
3. Sea-level canal is opened in 2000.
4. Payout is in 2060.
5. Low tonnage and 46% mix are assumed.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Toll of $0.884 per cargo ton assumed until sea-level canal construction is started.
8. Panama Canal assumed on standby for 10 years and then in mothballs.

ROUTE 10 SENSITIVITY OF TOLL TO PROJECT COST

FIGURE III-12



NOTES:
1. Route 10 construction schedule is assumed.
2. Royalty rate is $0.22 per cargo ton.
3. Sea-level canal is opened in 2000.
4. Payout is in 2060.
5. Potential tonnage and 25% mix are assumed.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Toll of $0.884 per cargo ton assumed until sea-level canal construction is started.
8. Panama Canal assumed on standby for ten years and then in mothballs.

ROUTE 10 SENSITIVITY OF TOLL TO PROJECT COST

FIGURE III-13

If sea-level canal operating experience shows that additional transit capacity cannot be secured any other way, a by-pass could be provided at a cost of $460 million. For the "potential" tonnage 25 percent freighter cargo mix projection, the by-pass would be ready for operation in 2025 after four years of construction. Figure III-14 illustrates the changes in cash flow if (a) toll levels were increased in 1975 to maintain payout date even if the by-pass became necessary, and (b) toll levels were maintained at former level and payout date were delayed if the by-pass became necessary.

Ranking of Canal Options

One way of ranking the canal options within the context of the "payout analysis" is by the average equivalent tolls per cargo ton which would have to be charged to liquidate the costs charged against that option after 60 years of operation. This ranking is shown in Table III-8 which assumes a 6% interest rate, start of operation of each new construction option in 2000, and a change of toll rate from the assumed rate of $0.884 per cargo ton to the required level at the start of construction of the option. The required tolls are given for both the "low" and the "potential" tonnage projections. The tolls listed with the "low" tonnage projection are considered more relevant in this analysis. A similar analysis was not done in connection with the "economic evaluation" since that analysis indicates that none of the sea-level canal options, nor the third lane of locks, provides a net commercial return sufficient to cover costs including amortization of the capital investment at a rate of interest approaching current Federal Government borrowing costs.

TABLE III-8
Canal Options Ranked by Self-Liquidating Tolls

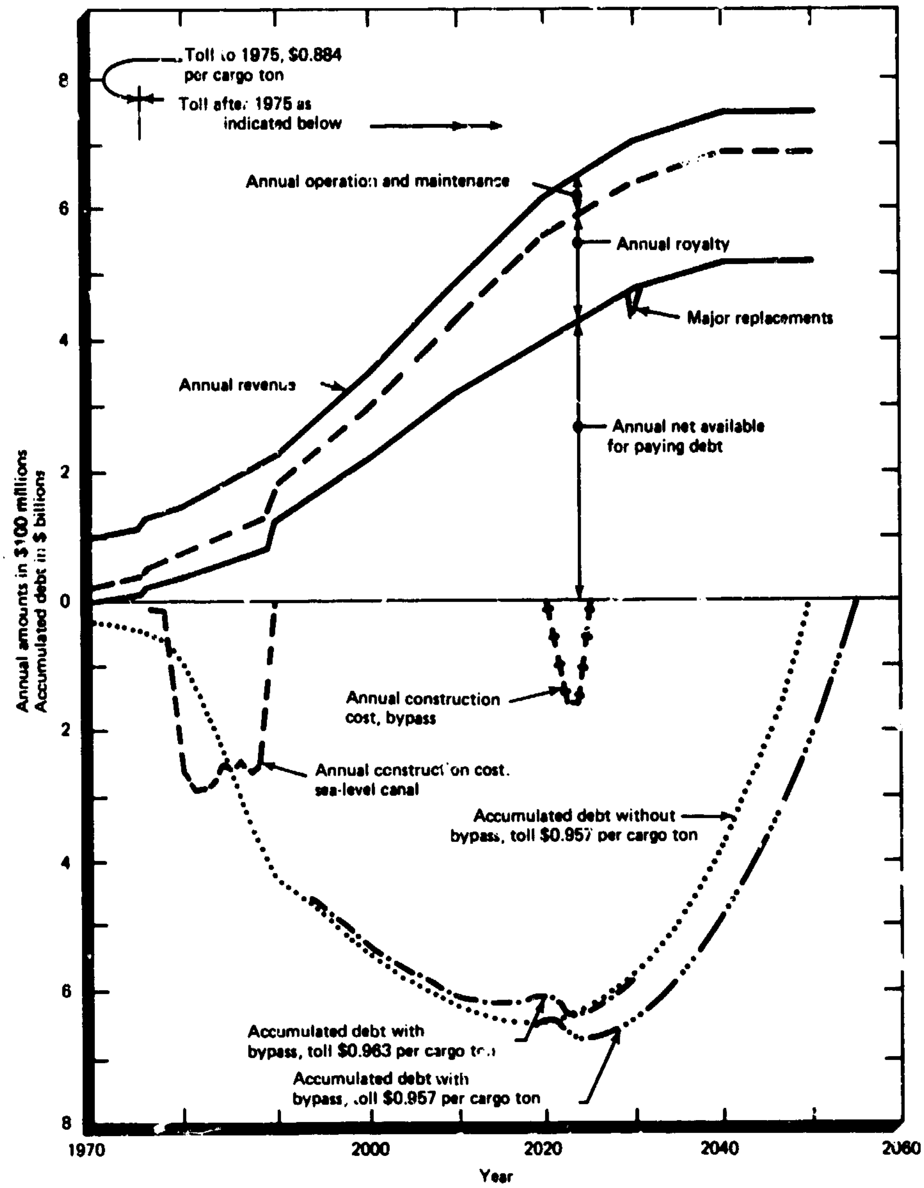
Canal Option	Required Tolls per Cargo Ton[1] "Low" tonnage projection	Required Tolls per Cargo Ton[1] "Potential" projection
Present canal improved as recommended by Kearney	$0.59[2,3]	$0.49[2,3]
Present canal improved as recommended by Kearney and existing locks replaced in 2000	0.85[2,3]	0.78[2,3]
Route 15	0.89[3,4]	0.70[3,4]
Route 10	1.02	0.78
Route 14S	1.09	0.82
Route 15 with existing locks replaced in 2000	1.12[3,4]	0.92[3,4]

[1] Royalties reach $0.22 per cargo ton in 1976, tolls change from $0.884 per cargo ton at the start of construction of the canal option, canal option in service in 2000, financing of the canal option assumed an extension of that of Panama Canal, and all debts liquidated with interest at 6% after 60 years of operation.

[2] Required tolls after liquidating the cost of Kearney improvements and current debt on which Panama Canal Company pays interest and including cost of Canal Zone Government.

[3] Tug charges of $0.02 per cargo ton added to values derived from analyses to make them comparable to those for sea-level canal options.

[4] Cost of Canal Zone Government included.



NOTES:

1. Construction cost $2.88 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. New canal opens in 1990 for payout in 2050.
5. Potential tonnage projection and 25% mix used.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Panama Canal kept on standby for ten years and then in mothballs.
8. Cost of bypass $460 million.

ROUTE 10 CASH FLOW ANALYSIS
EFFECTS OF A BYPASS

FIGURE III-14

Chapter IV

METHODS OF FINANCING

General

The lack of financial attraction as a purely commercial enterprise need not necessarily preclude construction of a sea-level canal. Many Federal capital projects do not generate revenues adequate to cover their costs and, therefore, would not meet the test of "economic" feasibility applied to the canal options in Chapter III. Rather, these projects have been justified by identifiable economic benefits, including benefits which produce no revenues for the project. As mentioned earlier, such benefits have not been identified with quantified values for inclusion in the economic evaluation of this Study. However, consideration could be given, even if on a judgmental basis, to charging a portion of the cost of new canal facilities against defense, foreign policy, and other objectives and benefits, thus reducing the capital investment reimbursable from commercial revenues.

Similarly, absence of overall economic feasibility need not bar private or foreign government participation in the project. However, questions of eventual ownership and control could affect the form of such participation, the amount of necessary subsidies, and the manner in which such subsidies were provided. Arrangements for financing, ownership, and control would, of course, have to be carefully examined from the point of view of protecting the financial interest of the United States, as well as its defense and foreign policy interests.

Manner of Providing Subsidies

To the extent necessary, Federal subsidies could be provided either as contributions during the construction period or annually over the economic life or amortization period of the project. To the extent that subsidies are justified on defense, foreign policy, shipping, or other grounds, proper accounting would suggest that appropriations for the subsidies be sought by and be reflected in the budgets of the Federal agencies with primary responsibilities for these areas.

Foreign Government Participation

It is not clear to what extent participation by foreign governments in the financing and control of the project would be consistent with U.S. defense and foreign policy objectives. Participation by foreign governments which are recipients of U.S. foreign aid would also raise a question as to whether the effect of such participation would not ultimately be to increase the amount of U.S. foreign aid otherwise required, resulting, in effect, in U.S. Government financing but loss of control over the operations. Purely economic and financial considerations, however, would not appear to preclude foreign government participation.

Private Participation

a. **By Users.** Private canal users could be required to buy stock in a canal corporation. The stock purchase requirement could be related to the number of transits, with the purchase price incorporated as a surcharge on the toll.

b. **By Others.** Stock in the canal corporation could be offered for sale to investors generally, including private users and foreign governments. If this approach were taken, however, it would appear necessary to increase the direct Federal subsidy in order to provide more adequate debt service coverage, offer U.S. Government guarantees, or hold out the prospect of attractive returns on equity. Alternatively, this approach might require a higher tolls structure.

Principal Alternatives

The considerable uncertainty regarding the economic and financial feasibility of the project as evidenced by the wide range of assumptions discussed in Chapter III, the questions raised above with regard to the consistency of private or foreign participation with the foreign policy and defense objectives, and the increased Federal subsidies which would be required in order to attract private investors may suggest that control and operation of the canal should be vested in an independent Federal agency. The Federal agency could be financed either directly by the Federal Government or by the issuance of its own obligations, with or without a guarantee by the Federal Government.

Direct Federal Financing

Direct Federal financing could be accomplished by interest-bearing appropriations to the canal agency or by authorizing the canal agency to borrow from the Treasury within limits established in appropriation Acts. Under either form of direct Federal financing, the enabling legislation should provide broad authority for the establishment of tolls adequate to meet the agency's financial commitments, and this authority should not be limited to the existing cargo carrying capacity basis.

To assure proper accounting, the enabling legislation should require that charges for the use of the canal be set at levels calculated to cover all costs of operating and maintaining the canal, including depreciation, payment of interest on the Federal capital, and return of the Federal investment over an appropriate amortization period, e.g., the 60 year period used as a basis for the economic evaluation and payout analyses in this Study. If the agency is authorized to borrow from the Treasury, the legislation could also limit the maximum maturity of any obligation issued to the Treasury to a period not to exceed the balance of the period of U.S. control. Under either form of direct Federal financing, interest and scheduled principal payments could be deferred, but any payments so deferred should themselves bear interest.

Federally Guaranteed Financing

The acceptability of the guarantee approach is dependent upon adequate revenue coverage of the debt service. Enabling legislation should require adequate coverage, since the guarantee should be a means primarily for facilitating the market borrowing and for securing a more favorable interest rate. That is, a guarantee should be looked upon as a means for assuring the marketability of the obligations and not as a disguised means for providing

additional Federal subsidies of an undetermined amount. The latter would be the result if the projected debt service coverage allowed no margin for overestimation of revenues or underestimation of costs.

Although a Federal guarantee may ensure the marketability of the revenue bonds so that the amount of coverage is not important from that viewpoint, some margin of coverage is desirable to avoid frequent recourse to the guarantee. Moreover, adequate debt service coverage will be reflected in a somewhat lower rate of interest on the market borrowings since investors may be reluctant to rely on a guarantee as the only security for their investment. If a situation should develop, moreover, in which frequent recourse had to be made to the Federal guarantee, this would likely be prejudicial to continued sound financing of the canal and could also indicate a failure to establish appropriate tolls.

For these reasons revenue after depreciation or after charges against depreciation allowances should be, as a minimum, one and one-half times debt service charges. In some circumstances, it may be possible to reduce the coverage requirement in the earlier years of operation, for example, if a fairly rapid build-up to 1-1/2 times coverage should be indicated by the financial projections. The margin could be used for financing a sinking fund bond retirement mechanism.

A higher debt service coverage requirement has the effect of raising the net project cost, and, therefore, would result in increasing the immediate amount of Federal subsidy needed. The additional subsidies made necessary by the higher debt service coverage requirement, as distinguished from the subsidy justified on defense, foreign policy, or other grounds, could be provided in the form of direct Federal loans the repayment of which would be subordinate to the repayment of the guaranteed obligations. In particular instances, an unsatisfactory debt service coverage may be corrected to a limited degree by some extension of debt amortization schedules. This could probably be accomplished at the present time without any substantial increase in interest costs because changes in the interest rate curve become increasingly flat in the long-maturity area. The alternatives, of course, are an increase in the overall tolls structure, or in the amount of Federal subsidy. A relatively small increase in subsidy could have a significant leverage effect on debt service charges.

The debt service coverage requirement also implies the desirability of a call feature on the revenue bonds after adequate provision for a sinking fund or reserve fund. Excess revenues could then be applied to the early retirement of outstanding debt and thus shorten the amortization period and reduce the overall interest cost to be borne by the project.

As an additional prerequisite for Federal guarantees, it would be necessary to obtain certain "self-enforcing" financing arrangements; specifically, the enabling legislation should grant the canal operating entity broad authority to set tolls at levels sufficient to cover all costs including debt service. Any subsidies deemed necessary for particular types of canal traffic should be provided by direct appropriations for this purpose to the interested Federal agency, e.g., Department of Defense with respect to military vessels, Department of Commerce (Maritime Administration) with respect to other U.S. flag vessels, Department of State with respect to foreign vessels.

It would be desirable to have funds immediately available to cover the contingent liability assumed by the guarantees to avoid the risk of delays in meeting any liability. This could be done through advance appropriations, or by authorizing the canal operating entity to borrow from the Treasury in amounts sufficient to make good on the guarantee. In any

event, Federal payments with respect to a guarantee should be treated as repayable advances to the canal operating agency, and interest should be charged in accordance with the current market yields on direct Treasury obligations of comparable maturity. Enabling legislation should vest in the Secretary of the Treasury authority to approve the issuance of debt obligations by the canal agency. Such approval should extend to the amounts, interest rates, timing, other terms, and debt service coverage, in order to provide for the coordination of the canal agency's borrowings with other Federal financing and to protect the financial interests of the United States under the guarantee.

Interest Costs Under the Two Alternatives

It has always been difficult to predict movements in market interest rates even over relatively short periods of time. Longer-run predictions—under some of the options canal construction need not begin prior to 1990—are even more hazardous. Currently, interest rates are at historic highs, and have risen with only minor interruptions for over a generation.

On the demand side, a substantial backlog of unmet credit demand exists. State and local governments alone in 1969 postponed or deferred about $3 billion of authorized debt issues. While the amount of borrowing deferred by other borrowers has not been tabulated, it is clear from the rate of new mortgage originations, for example, that individuals have deferred a substantial amount of borrowing for housing purposes. To the existing backlog of unfilled borrowings must be added potential future demands for credit. In the area of public investment, an area in which needs are determined largely on the basis of considerations other than economic and thus are less sensitive to interest rate movements, it is easy to visualize a substantial demand for such debt-financed projects as environmental pollution control facilities, public housing, education, health, and public transportation facilities. In view of the substantial current backlog and potential future demand, barring a deep recession which it seems clear no Administration would allow to develop, it is difficult to foresee any significant long run reduction in the demand for credit, either relatively or absolutely.

On the supply side, the 5 year projections in the Budget and Economic Report appear to indicate that the Federal Government will not be a significant net saver and supplier of funds at least in the near future. Moreover, the increased stability of the economy, in terms of freedom from significant recession, and the expansion of income maintenance programs may well reduce the incentive for individuals to save, and could result in less than proportionate increases in private savings as the economy expands.

In view of the foregoing, it is difficult to anticipate any significant secular reduction in interest rates. Under current market conditions, taking into consideration the yields on outstanding Treasury, Federal agency, and corporate obligations, the cost of direct Federal financing of the canal project would appear to be approximately 8 percent, although rates in the range of 6 - 9 percent might reasonably be considered. Short-term market changes may lead to some modification of this conclusion, but it is based largely on the secular considerations previously described.

Federally guaranteed financing would require a higher interest rate than direct Federal financing. Although a full Federal guarantee provides the same assurance of safety of principal as the investor obtains in Treasury obligations, the investor must also look to the

strength of any legal assurance of timely payment, loss of liquidity because of the thinness of the market, and other factors. Under current market conditions, a Federal agency well established in the market could expect to borrow at a rate approximating one-half of one percent over the Treasury borrowing rate. Moreover, experience with existing programs indicates that investors in guaranteed issues also look to the underlying viability of the project or program being financed. The uncertainties surrounding the viability of the canal project, the long period from the initiation of construction to the beginning of significant payment, and the above-mentioned marketing considerations suggest that an interest rate approaching 9 percent would be required for Federally guaranteed financing.

It is not obvious that any advantage claimed for Federally guaranteed financing would be sufficient to justify the higher cost of financing under this method. It is sometimes argued that a project should be financed by issuing its own obligations in the market in order to assure that the project meets the "test of the market." If direct Federal subsidies are required in any event, however, the "market test" argument loses some of its force. Moreover, the higher financing costs would require greater Federal subsidies, or could result in the need for direct Federal subsidies to otherwise marginally self-supporting canal options.

Attempts have been made to justify the higher financing costs of agency market borrowing in terms of additional "flexibility", usually meaning freedom from the statutory ceiling on the public debt and from budget controls. Under current budget accounting rules, outlays by Federal agencies from the proceeds of obligations issued in the market are counted as Federal outlays in the budget, and it would be difficult to argue that the canal project should be exempted from the normal budget review process. On the other hand, the so-called "market test" may be the most effective mechanism for assuring that the financing of the canal does not become a heavier burden on the general taxpayer than intended at the time the decision is made.

Chapter V

CONCLUSIONS

The following are the major conclusions derived from this Study:

1. Long-range estimates of potential revenues, construction costs, operating expenses, and interest rates are tenuous and subject to unforeseeable changes.
2. If viewed as a commercial enterprise (e.g., within the context of the economic evaluation in this Study), in which a new canal option is considered as an incremental development to the existing transisthmian canal facilities and only those revenues associated with traffic beyond the capacity of the existing Panama Canal are considered in the evaluation, investment in a sea-level canal or a third locks option cannot be justified.
3. If subjected to a more limited type of financial analysis (e.g., the payout analysis contained in this Study), in which total interoceanic revenues are dedicated to the payment of operation and maintenance costs and amortization of the construction debt of new transisthmian canal facilities. the costs of a sea-level canal or a third locks option could be amortized by tolls revenues under certain conditions, even if the "low" tonnage projection were to materialize. These include the following: combining the financing of the sea-level canal with that of the Panama Canal, initiation of construction no earlier than 1985, a moderate increase in toll rate for the existing canal upon initiation of construction, and charging the canal operating agency interest at a rate below the current cost of Treasury borrowing.
4. Financial and other considerations indicate that responsibility for construction and operation of a sea-level canal should be vested in an independent agency of the U.S. Government which should be financed directly by the Government.
5. The payout analysis includes basic considerations for development of an outline financial plan. However, development of a detailed financial plan for new canal facilities must await implementing decisions reflecting such matters as treaty terms, possible revisions in the tolls system, and financing arrangements.

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Appendix 1

PAYOUT ANALYSIS

Purpose

This Appendix presents the detailed results of analyses of cost and revenue data which were undertaken in order to illustrate combinations of assumptions under which the costs of a new interoceanic canal could be amortized after a period of 60 years of operation. The analyses are based on assigning total interoceanic revenues to the payment of operation and maintenance costs, royalties and the amortization of debts attributed to existing and new facilities. Panama Canal revenues, operation and maintenance costs, improvement costs, and the debt on which interest is paid to the United States Treasury are considered in the analyses. This Appendix contains the detailed studies referred to under "Payout Analysis" in Chapter III. It does not include consideration of the "Economic Evaluation" described in the same Chapter.

Method

The analyses consist essentially of synthesizing a year-by-year bookkeeping operation extending from the start of design and construction (or earlier) and ending 60 years after initiation of operation of the new canal facilities. All the basic information presented in Chapter II on costs and revenues are reduced to annual values for purposes of the analyses. Two basic statements define the bookkeeping as follows:

> The debt at the end of the year equals the debt at the beginning of the year plus the cost of capital improvement during the year, and annual interest; less the remainder from gross revenues after payment of royalty, operation and maintenance costs, and any major replacement.
>
> Annual interest during the year equals the debt at the beginning of the year times the interest rate for the whole year, plus the cost of capital improvement during the year times the interest rate for one-half of the year.

Not all of the expenditures mentioned in the foregoing statements occur in every year of the analyses.

The analyses determined the tolls after payment of royalty that would permit paying off all debts with interest at various assumed rates after the new facilities had been in operation for 60 years. The general method was varied as necessary to explore the effect of the following on toll rates necessary to permit payout after 60 years of operation:

1. The various canal options under consideration.

2. Separation of the costs and revenues of the sea-level canal options from those of the Panama Canal so that net revenues of the latter would not be available for defraying construction costs of a sea-level canal until the sea-level canal is placed in operation.
3. Combination of the costs and revenues of the canal options including Route 15 and its locks with those of the Panama Canal, making net revenues of the latter available for defraying construction costs.
4. Variation between the "potential" and the "low" tonnage projections of the Shipping Study.
5. Variation of the date when the canal option is placed in operation.
6. Variation of the date when the tolls are changed from the assumed rate of $0.884 to the rate required to liquidate all costs of both the existing canal and the new canal option.
7. Variations in reimbursable cost.
8. Variations in the interest rate charged on reimbursable capital.
9. Variations in project transit capacity.

The analyses were programmed for solution by automatic data processing equipment. This permitted rapid solution of any given set of conditions to determine the payout date with a trial toll rate. The computations were repeated until the toll rate which permitted payout in 60 years was solved directly or could be interpolated. The program permitted various inputs to reflect the variations enumerated in the previous paragraph. The output could be varied according to the objective of the computation.

Under the existing Panama Canal toll assessment system, tolls are levied on the basis of cargo carrying space or ship displacement and not on the basis of cargo tonnage actually carried. In this Appendix, projected interoceanic revenues are expressed in terms of toll rates or dollars per cargo ton as an analytic and expository expedient for relating revenues to projected cargo tonnages. This procedure involves the use of a constant toll rate over the period of analysis regardless of changes in the proportion of cargo carried in freighters, dry bulk carriers and tankers. Under the existing Panama Canal toll assessment system, in contrast, if the Shipping Study potential tonnage, 25% freighter cargo mix forecast materializes revenue per cargo ton would decrease from the current rate of $0.884 to $0.777 per cargo ton in the year 2000 as the proportion of freighter cargo declined from the current 46% to 25%. Use of this analytic and expository expedient in this Appendix should not be interpreted as advocacy of a change in the existing toll assessment system.

Appendix Presentation

The results of the studies are presented, with minor exceptions, on three types of display sheets entitled as follows:

1. "Toll Per Cargo Ton vs. Canal Opening Date." Separate curves of this type are presented for Routes 10, 14S and 15, for financing separated from that of the Panama Canal and combined with it, and for toll rate change dates at the start of operation of the canal option and the start of construction of the canal option. Each sheet has curves for the two projections of transisthmian canal cargo tonnage.

2. "Cash Flow Analysis." These sheets are used to demonstrate the variations with the years of annual revenues, annual operation and maintenance cost, annual royalty, and net revenue available for debt service; annual construction cost; and the accumulation of debt during construction and liquidation after 60 years of operation. Curves are shown for Routes 10, 14S and 15 for selected conditions. An interest rate of 6% is used on all curves of this type.
3. "Sensitivity of Toll to Project Cost." Individual curves are presented for Route 10 for "low" and "potential" tonnage projections, for completion dates of 1990 and 2000, and for two toll rate changing dates, at several interest rate levels.

This Appendix discusses first the effects of separating or combining the financing of the sea-level canal options from the revenues, costs and debts of the Panama Canal. This is followed by a discussion of Route 10 in considerable detail with references to curves as appropriate. Route 14S is then discussed at less length because the analyses are similar to those for Route 10. Route 15 comes next, followed by a discussion of continued operation of the Panama Canal. The last analysis compares the various canal options on the basis of tolls which would have to be charged to make the options self-liquidating after 60 years of operation. The Appendix concludes with a summary.

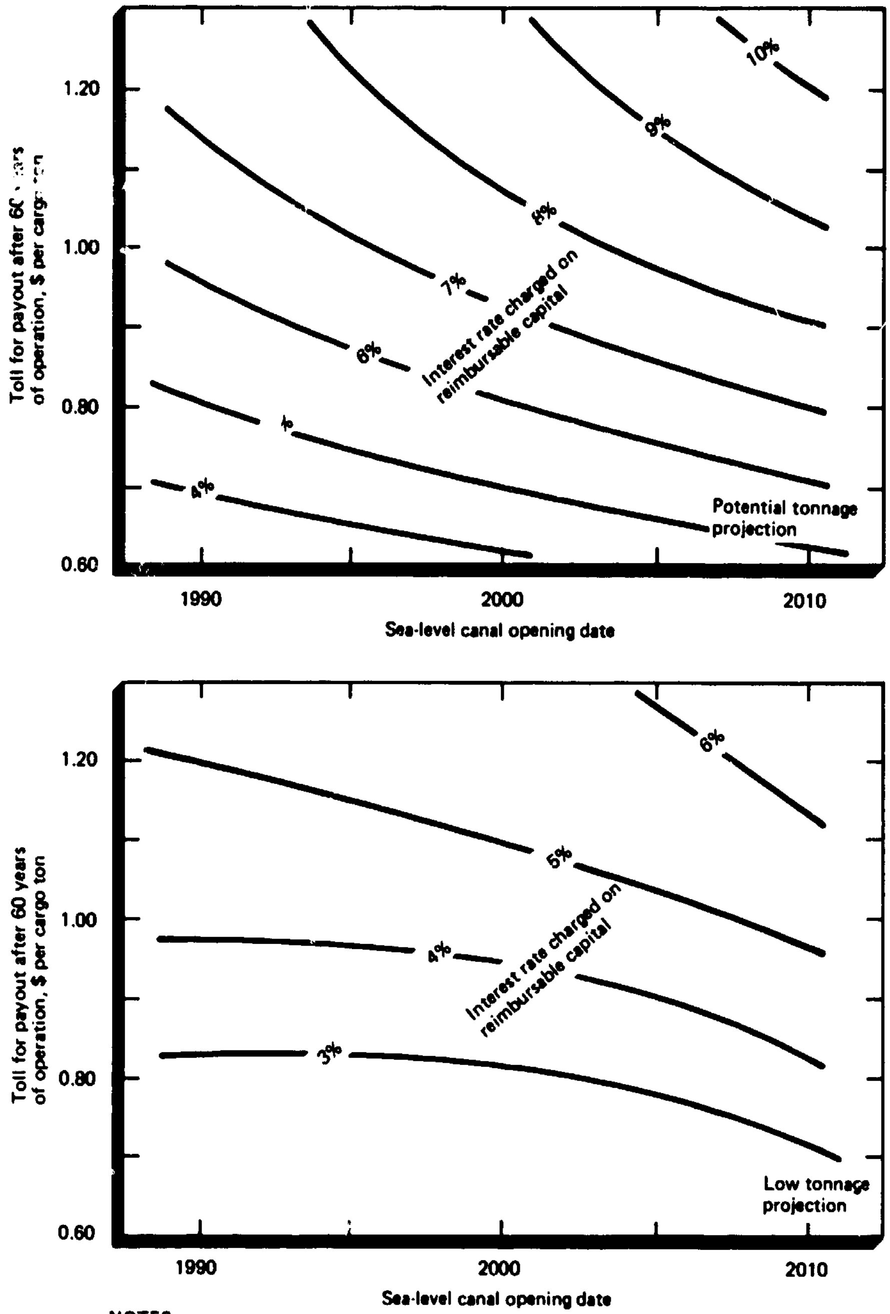
Financing Separated or Combined with That of The Panama Canal, Route 10

The most favorable circumstance for amortizing the costs of the various canal options has been taken as the lowest toll rate which would permit liquidating all debts after 60 years of operation, assuming a particular interest rate. The tolls required with the "low" tonnage projection are considered more relevant than those with the "potential" projection. The most favorable conditions prevail generally if the financing of the canal option were combined with the revenues, costs and debt of the Panama Canal rather than being considered separately from the revenues and costs of the Panama Canal. This is illustrated in Figures A1-1 and A1-2 and Table A1-1.

The advantage of combined financing results from the fact that net revenues from the operation of the Panama Canal can be used effectively to defray the construction costs of the new canal option. This advantage does not occur with early (1990) completion of Route 10 because the Panama Canal Company debt and the cost of the improvement program[1] would not have been liquidated by the time construction of Route 10 would be completed. (See Figure A1-28). This is reflected in the higher tolls under combined financing than for separate financing in connection with the 1990 completion date shown in Table A1-1. Early completion of Route 10, however, is not favorable because interest rates of 6% or more cannot be supported with the "low" tonnage projection within the $1.30 upper limit used on toll rates for this study.

On the basis of the foregoing, no further consideration is given in the succeeding discussions to financing which separates the revenues and costs of the Panama Canal from those of the canal options.

[1] Recommended in "Improvement Program for the Panama Canal, 1969" by A. T. Kearney and Company, Inc.

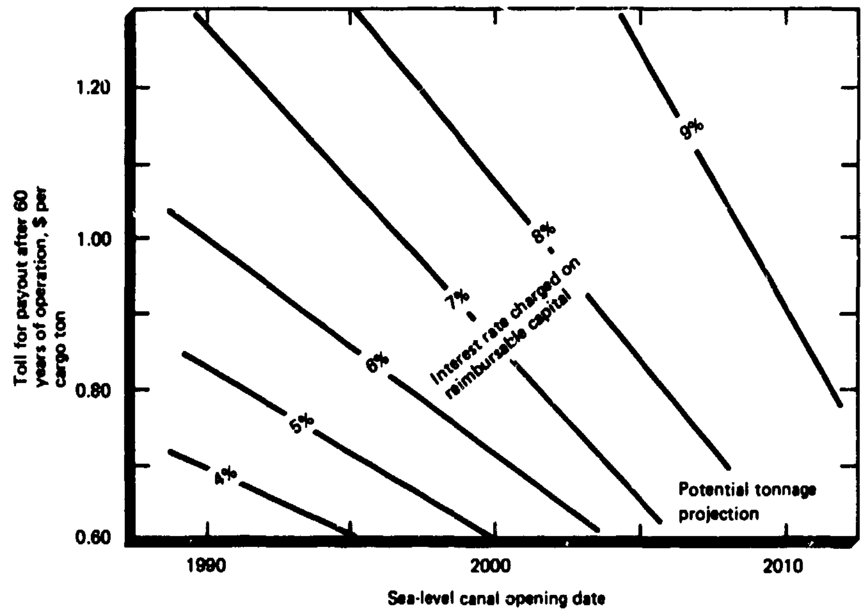


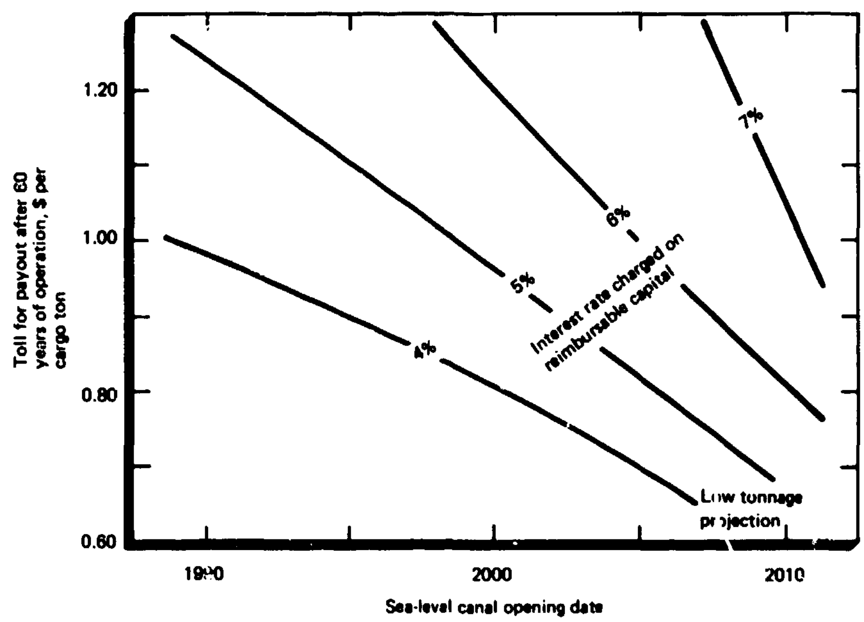
NOTES:

1. Sea-level canal financing is assumed to be separate from Panama Canal financing.
2. Panama Canal assumed on stand-by for 10 years after sea-level canal is opened, and in moth-balled state thereafter.
3. Route 10 cost is $2.88 billion.

ROUTE 10 TOLL PER CARGO TON VS. CANAL OPENING DATE

FIGURE A1-1





NOTES:
1. Canal financing assumed an extension of that of the Panama Canal with a debt of $317 million in 1970.
2. Toll of $0.884 per cargo ton assumed until sea-level canal opens.
3. Panama Canal assumed on standby for 10 years, and then in mothballs.
4. Route 10 cost is $2.88 billion.

ROUTE 10 TOLL PER CARGO TON VS. CANAL OPENING DATE

FIGURE A1-2

TABLE A1-1
ROUTE 10
Self-liquidating Toll,
Financing Seperate and Combined
with Panama Canal

Year Route 10 opens	Interest rate	Tonnage projection	Toll per cargo ton Financing Separate[1]	Combined[2]
1990	5	Potential	$0.81	$0.82
1990	5	Low	1.20	1.24
2000	5	Potential	0.70	0.60
2000	5	Low	1.10	0.96
2010	6	Potential	0.70	[4]
2010	6	Low	1.12	0.81

[1] Net revenues of Panama Canal not available for defraying construction cost of Route 10. Operation of Panama Canal stopped on completion of Route 10 and all revenues from transisthmian traffic accruing to Route 10 after that time.
[2] Net revenues of Panama Canal available for defraying construction cost of Route 10. Same as (1) on completion of Route 10.
[3] Highest interest rate which can be compared from Figures A1-1 and A1-2.
[4] Value is less than the lower limit of $0.60 shown on Figures A1-1 and A1-2.

Other Analyses, Route 10

Toll Change Date.

Tolls, if set in accordance with the "low" tonnage projection, would have to be increased from the current levels to defray all costs within 60 years of operation of the new canal option. The advantage of using net Panama Canal revenues to defray construction costs would be enhanced the earlier the Panama Canal tolls are increased. Also, the earlier the toll rate change is made the less the required increase. Figure A1-2 assumes that toll rates are changed when Route 10 is placed in operation. Figure A1-3 assumes that toll rates are changed when construction of Route 10 is started or 15 years before it is placed in operation. Table A1-2 compares these two figures.

It will be noted that in the cases where toll rates can be lowered from the $0.884 assumed to prevail before the toll rate change date, the late change will produce the lower self-liquidating toll. This is explained by the fact that the early change spreads the toll rate change over a longer period of time and thus makes a smaller toll rate change necessary. With a lowering of toll rates, the early change results in a smaller lowering and, consequently, a greater toll rate than would be the case with the late toll rate change.

Cash Flows, Route 10

Figures A1-4 through A1-7 are cash flow diagrams illustrating the status of the canal books, assuming 6% interest. Figure A1-4 shows what might happen if "potential" tonnage

TABLE A1-2
ROUTE 10
Effect on Self-liquidating Tolls of Various Toll Change Dates

Year Route 10 opens	Interest rate	Tonnage projection	Toll per cargo ton Toll change date Early[1]	Late[2]
1990	6%	Potential	$0.94	$1.00
1990	6%	Low	1.19	[3]
2000	6%	Potential	0.75	0.71
2000	6%	Low	1.03	1.20
2010	7%[4]	Potential	0.64	[5]
2010	6%	Low	0.83	0.81

[1] Toll changed when construction of Route 10 is started. Toll assumed at $0.884 per cargo ton until that date.
[2] Toll changed from $0.884 per cargo ton when Route 10 is placed in operation.
[3] More than $1.30.
[4] 7% selected to show the differences.
[5] Less than $0.60.

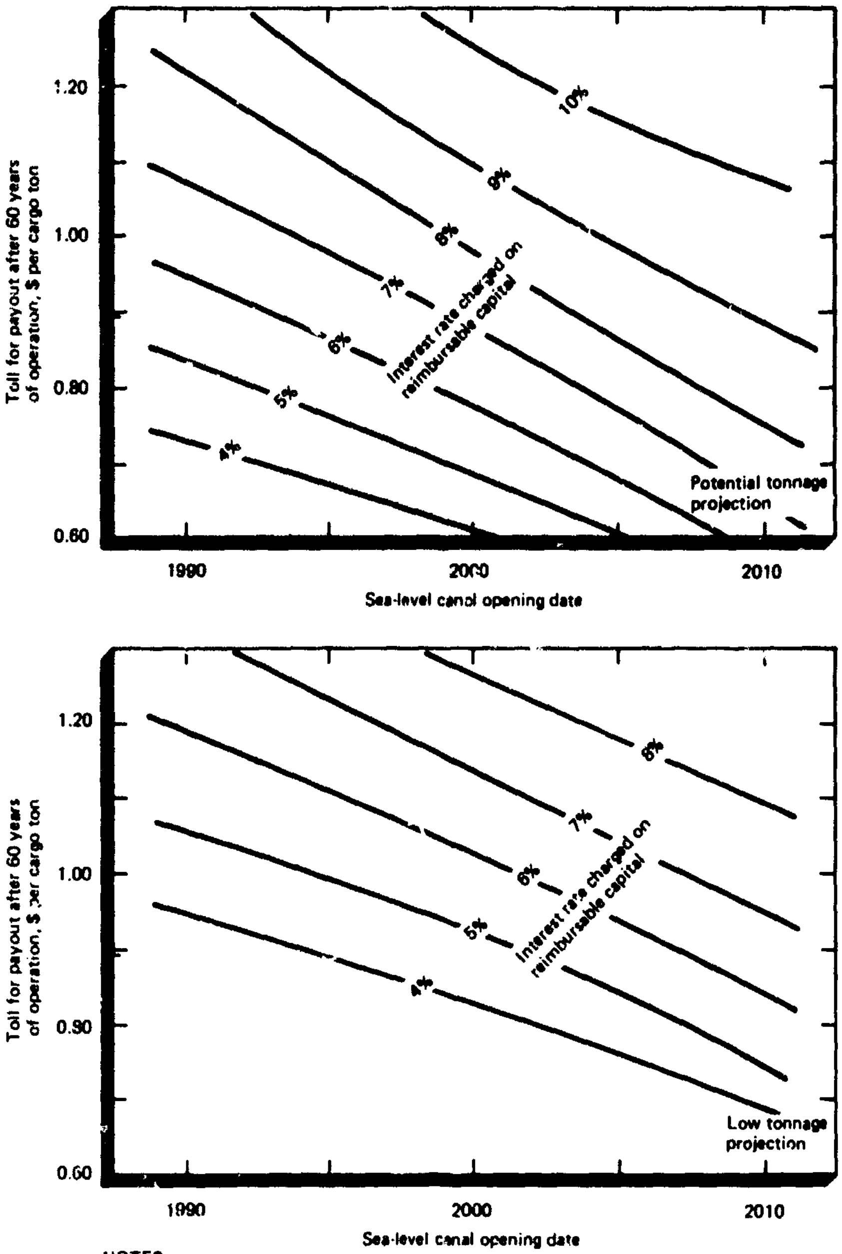
growth prevailed and Route 10 were placed in operation in 1990, at which time the toll rates were changed to the level required for all debts to be liquidated by 2050. The required toll rate would amount to $1.00 per cargo ton. The maximum canal debt, about $6.8 billion, would be reached about year 2017. Also shown in Figure A1-4 are the effects on canal debt of changes in interest rates and toll rates. If toll rates were $0.10 higher than that required for self-liquidation, payout would occur about 21 years earlier. An increase of 0.5% in interest rate or a $0.10 decrease in toll rate would cause the debt to increase exponentially with no payout.

Figure A1-5, when compared with Figure A1-4, shows the effect which a delay in completion date to year 2000 has on tolls and debt. The comparison is made in Table A1-3.

TABLE A1-3
Route 10
Comparison of Early and Late Completion Dates

Item	Completion Date 1990	2000
Self-liquidating toll[1] per cargo ton	$1.00	$0.71
Peak debt in billions	$6.8	$4.3

[1] Tolls changed from assumed $0.884 to the self-liquidating toll when Route 10 is placed in service, 6% interest, potential tonnage.

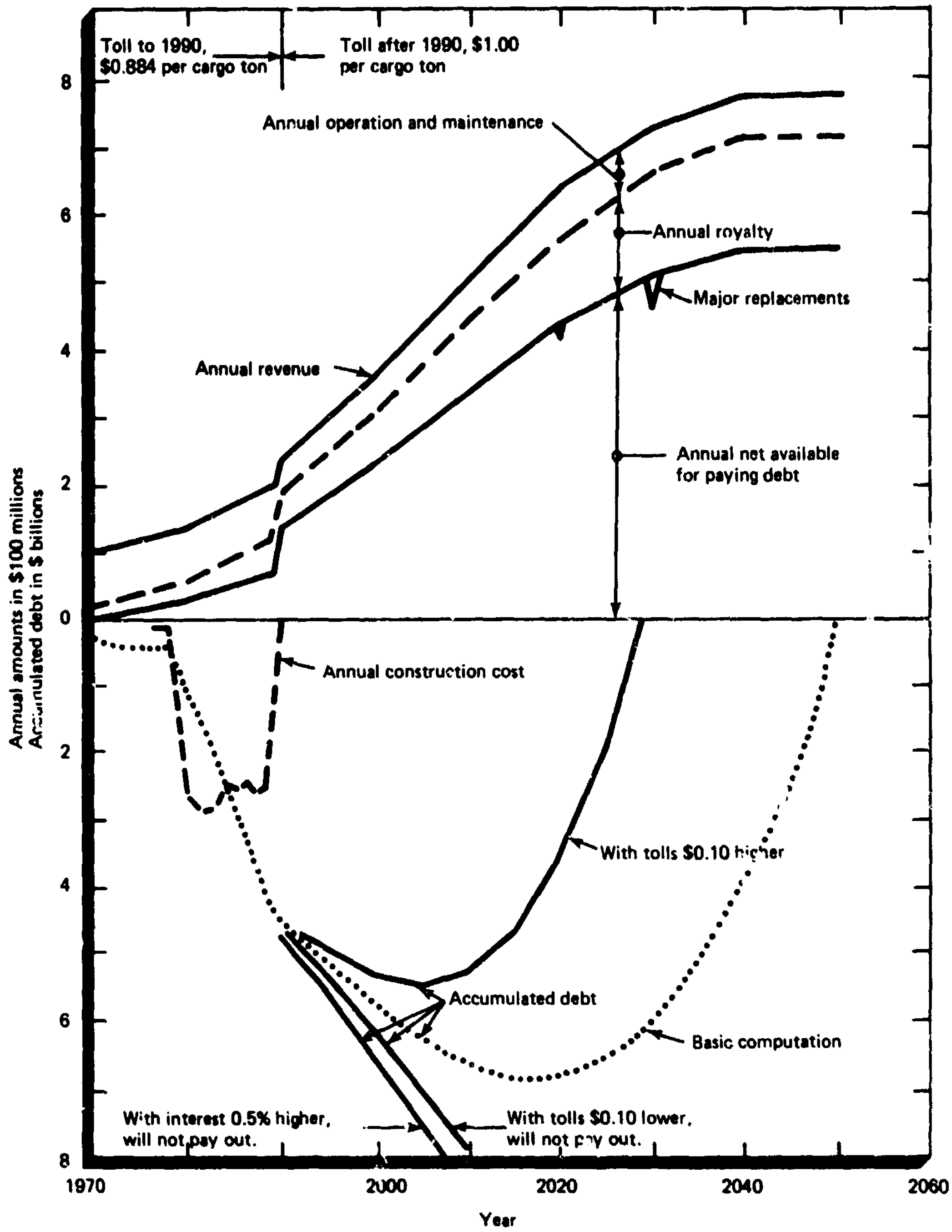


NOTES:

1. Canal financing assumed an extension of that of the Panama Canal with a 1970 debt of $317 million.
2. Toll of $0.884 per cargo ton assumed until canal construction is started.
3. Panama Canal assumed on standby for ten years, and then in mothballs.
4. Route 10 cost is $2.88 billion
5. Royalty reaches $0.22 in 1976.

ROUTE 10 TOLL PER CARGO TON VS. CANAL OPENING DATE

FIGURE A1-3

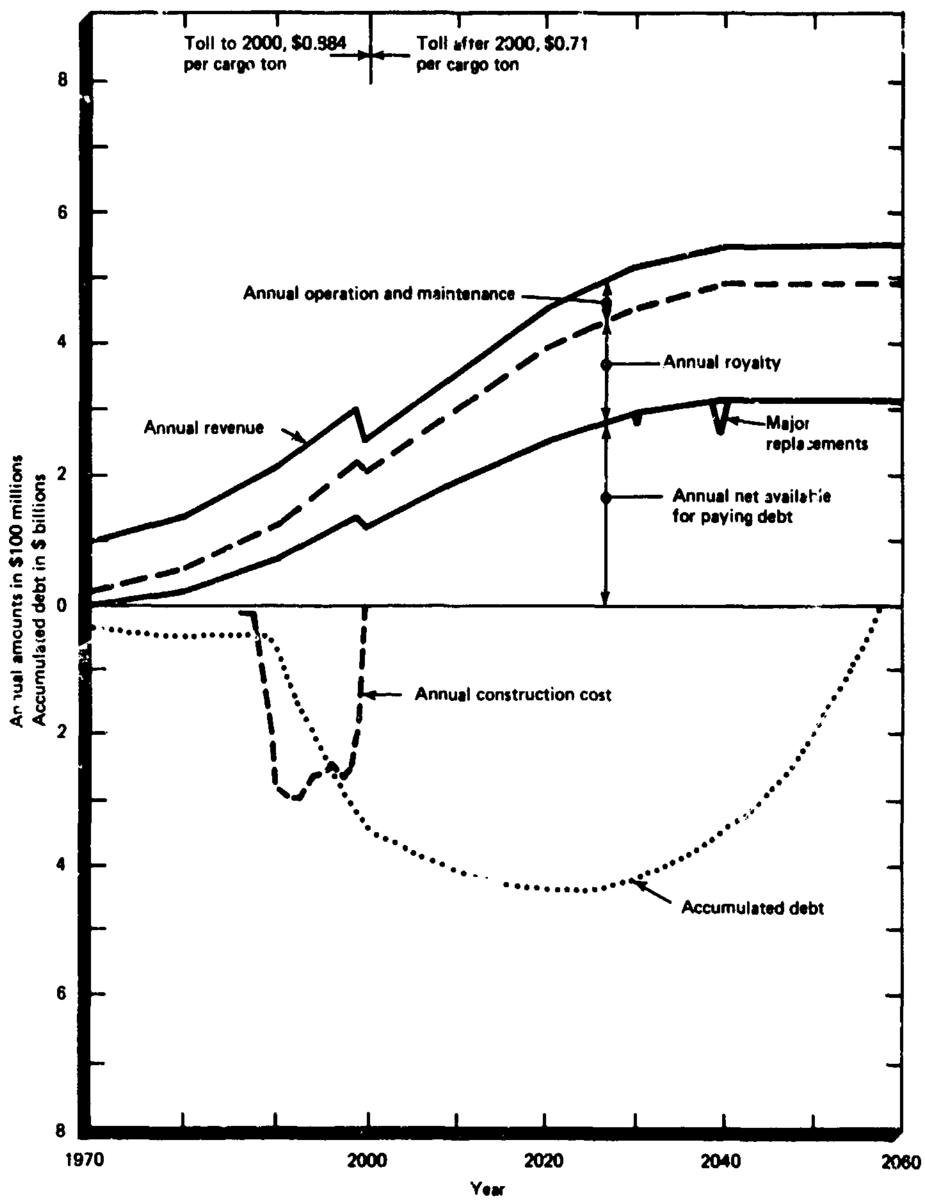


NOTES:

1. Construction cost is $2.88 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. New canal opens in 1990 for payout in 2050.
5. Potential tonnage projection and 25% mix used.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Panama Canal kept on standby for 10 years and then in mothballs.

ROUTE 10 CASH FLOW ANALYSIS

FIGURE A1-4



NOTES:
1. Construction cost is $2.88 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. New canal opens in 2000 for payout in 2060.
5. Potential tonnage and 25% mix used.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Panama Canal kept on standby for 10 years and then in mothballs.

ROUTE 10 CASH FLOW ANALYSIS

FIGURE A1-5

Figure A1-6, when compared with Figure A1-4, shows the effect which the date on which toll rates are changed has on tolls and debt. The comparison is made in Table A1-4.

TABLE A1-4
ROUTE 10
Comparison of Early and Late Toll Change Dates

Item	Toll change date 1975[1]	Toll change date 1990[2]
Self-liquidating toll[3] per cargo ton	$0.96	$1 00
Peak debt in billions	$6.5	$6.8

[1]Start of construction.
[2]Start of operation.
[3]Tolls prior to change assumed at $0.884, interest 6%, potential tonnage.

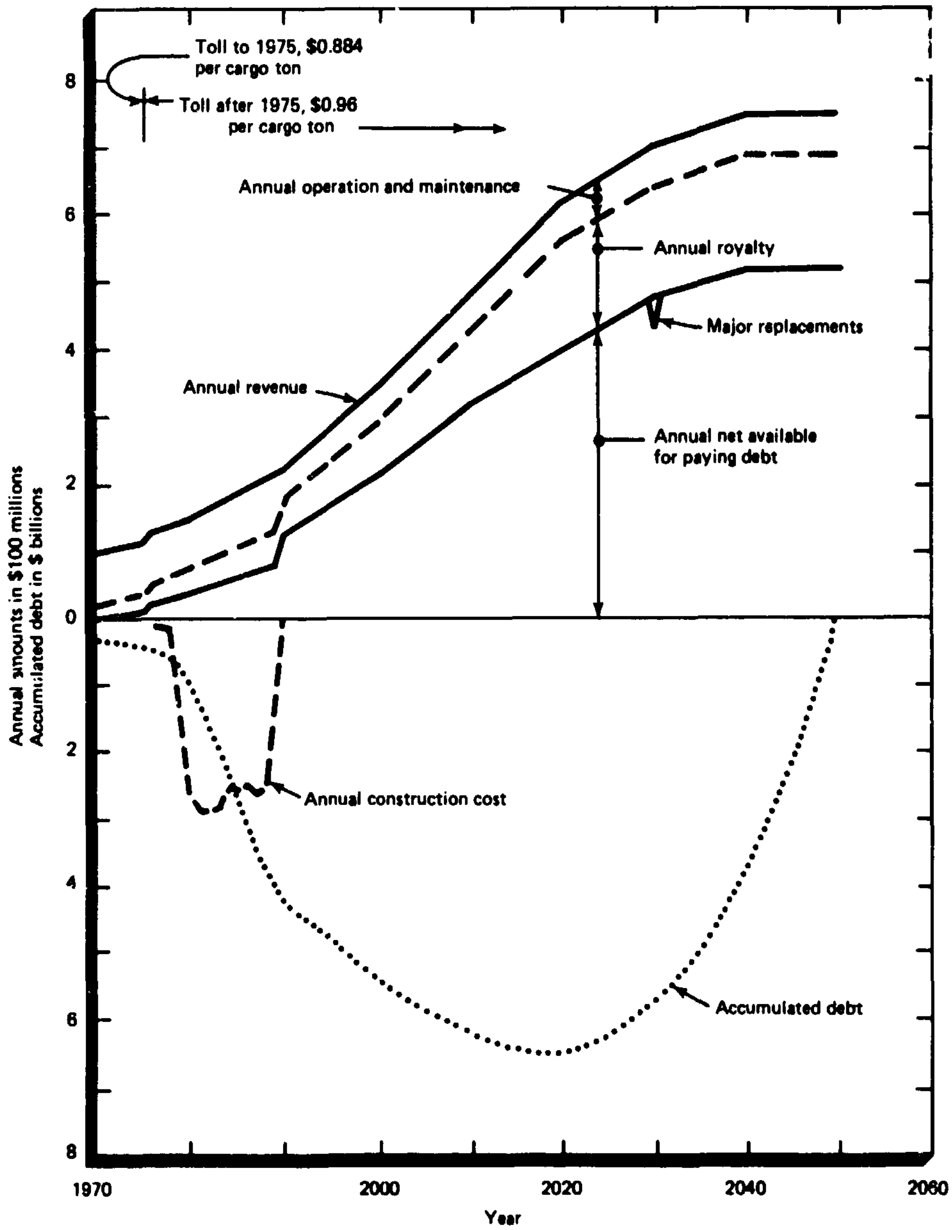
Figure A1-7, compared to Figure A1-4, shows the effect of both late completion date and early toll rate change on tolls and peak debt. The comparison is made in Table A1-5.

TABLE A1-5
ROUTE 10
Comparison of Early Completion Date and Late Toll Change Date with Late Completion Date and Early Toll Change Date

Item	1990 completion date and 1990 toll change date	2000 completion date and 1985 toll change date
Self-liquidating toll[1] per cargo ton	$1.00	$0.78
Peak debt in billions	$6.8	$6.1

[1]Toll prior to change assumed at $0.884, interest 6%, potential tonnage.

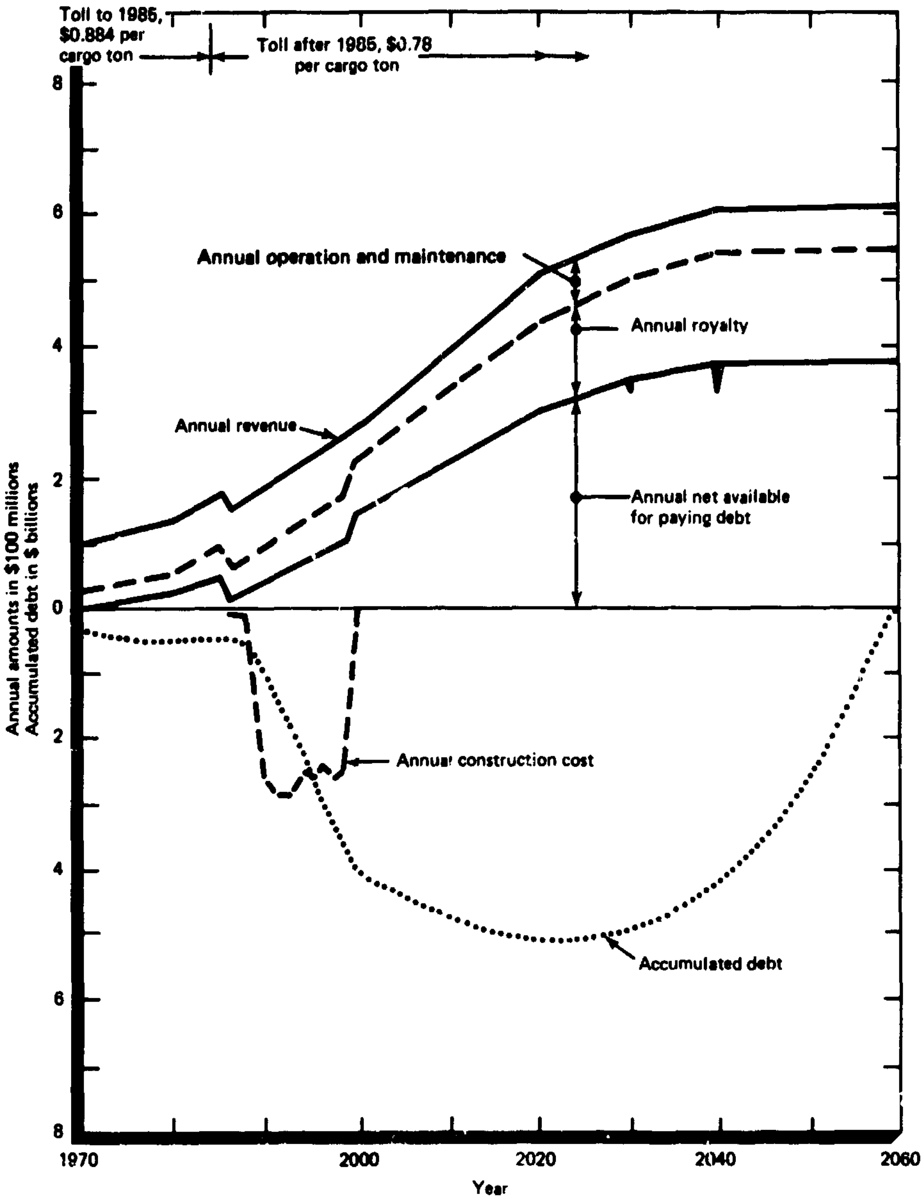
The studies to this point indicate that delaying the date of construction has a greater effect on reducing self-liquidating tolls than changing the toll rate at an early date. The latter factor lowers self-liquidating tolls only if it is necessary to increase toll rates from the $0.884 level assumed prior to the toll rate change.



NOTES:
1. Construction cost $2.88 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. New canal opens in 1990 for payout in 2050.
5. Potential tonnage projection and 25% mix used.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Panama Canal kept on standby for ten years and then in mothballs.

ROUTE 10 CASH FLOW ANALYSIS

FIGURE A1-6



NOTES:

1. Construction cost is $2.88 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. New canal opens in 2000 for payout in 2060.
5. Potential tonnage and 25% mix used.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Panama Canal kept on standby for ten years and then in mothballs.

ROUTE 10 CASH FLOW ANALYSIS

FIGURE A1-7

Figures A1-8 and A1-9 illustrate the effect on cash flows for "potential" and "low" tonnages of using toll yield as $1.30 per cargo ton. This approximates the upper limit of tolls presented in the Shipping Study. The figures assume that construction of Route 10 is started in 1975 at which time toll rates are increased to $1.30 per cargo ton. The sea-level canal is assumed to commence operation in 1990. With "potential" tonnage, the peak debt is about $2.9 billion and payout occurs after 17 years of operation. With "low" tonnage, the peak debt is about $2.8 billion and payout is after about 30 years of operation.

Since the Shipping Study indicates that the "low" tonnage projection is as likely as the "potential" projection, it would be prudent to base toll rates on the former. Figure A1-10 illustrates cash flow if tolls were set on this basis, and if the "low" tonnage projection materializes. A late inservice date (2000) and an early toll rate change date (1985, at the start of construction) were selected to secure the most favorable conditions financially. The required toll rate is $1.02. The debt peaks at about $3.6 billion after 25 years of operation.

Figure A1-11 illustrates cash flow for approximately the same case as in Figure A1-10, except that the "potential" tonnage projection is used. The canal debt peaks at about $2.5 billion when Route 10 is placed in service and declines rapidly afterward. Payout would occur in about 15 years. Figure A1-11 illustrates that payout would be extended to about 60 years after start of operation if toll rates were reduced to $0.43 in 2010.

Sensitivity of Peak Debt to Toll Rates and Opening Dates, Route 10

Table A1-6 and Figure A1-12 illustrate the implications for the peak debt associated with a sea-level canal on Route 10 operated in conjunction with the Panama Canal for several combinations of toll rates and opening dates for the sea-level canal.

Sensitivity of Self-liquidating Tolls to Reimbursable Costs, Route 10

The cost to be reimbursed from toll revenues might differ from the $2.88 billion presently estimated construction cost of a sea-level canal on Route 10 for a number of reasons. These include the following:

1. The cost of the canal might change during the design stage because of the additional foundation information which would become available from design stage explorations.
2. Part of the construction cost might be charged against presently unevaluated benefits, thus reducing the amount to be reimbursed from tolls revenues.
3. Part of the construction cost might be determined to constitute a subsidy, reducing the cost to be reimbursed from tolls revenues.
4. The channel size might be changed.
5. Treatment of present Canal investment might be altered.

Analyses were undertaken to determine the effect of variations in reimbursable costs on toll rates necessary to achieve payout after 60 years of operation at several interest rate levels. Table A1-7 lists the basic assumptions for Figures A1-13 through A1-18, which present the results.

The figures can be used as described below for Figure A1-13. Route 10, completed in 2000 at a cost of $2.88 billion, would be self-liquidating after 60 years of operation at a 6% interest rate if a toll rate of $1.02 per cargo ton were charged from the beginning of construction and maintained over the 60 year period of operation. (The line identified as 6%

TABLE A1-6
ROUTE 10

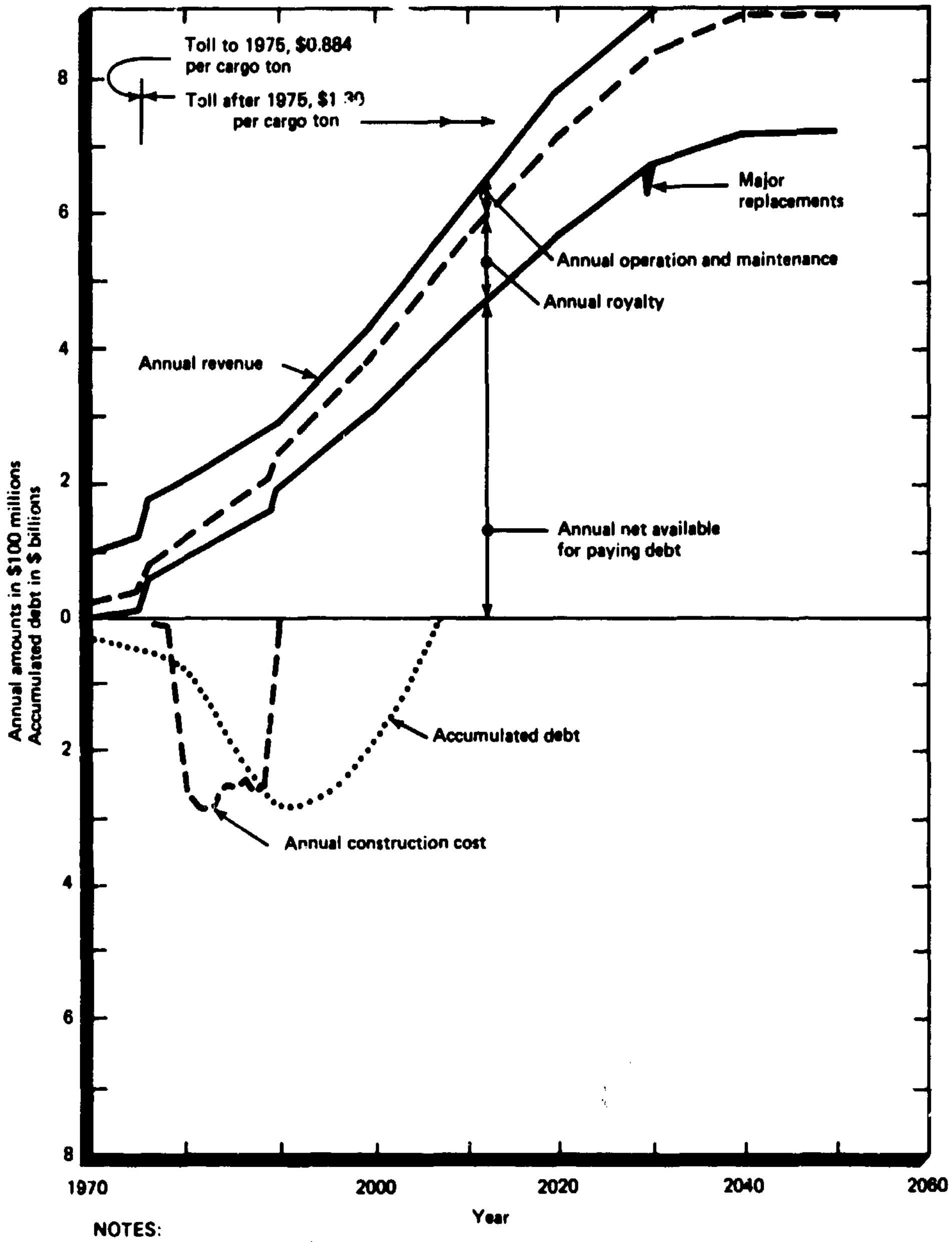
Estimated Peak Debt for a Sea-Level Canal on Route 10 Operated in Conjunction with the Panama Canal (Billions of dollars)

Toll per cargo ton	Low Tonnage Forecast Canal Opening Date 1990	1995	2000	Potential Tonnage Forecast Canal Opening Date 1990	1995	2000
$0.80	585.6*	382.2*	225.5*	303.8*	102.9*	4.4
0.90	419.6*	246.5*	116.1*	87.4*	4.9	3.3
1.00	253.6*	110.8*	6.8*	5.2	3.6	2.7
1.10	87.5*	3.6	2.6	3.9	3.1	2.2
1.20	3.6	2.7	2.2	3.3	2.7	1.6
1.30	2.8	2.3	1.7	2.9	2.2	1.1

*Will not payout within 60 years of operation. Debt shown in debt in year 2080, end date of computations.
[1] Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
[2] Toll of $0.884 per cargo ton assumed until canal construction is started.
[3] Interest rate is 6%.
[4] Panama Canal assumed on standby for ten years, and then in mothballs.
[5] Route 10 cost is $2.88 billion.
[6] Royalty reaches $0.22 in 1976.

TABLE A1-7
ROUTE 10

Figure	Projection	In-Service Date	Toll Change Date
A1-13	Low	2000	1985
A1-14	Potential	2000	1985
A1-15	Low	1990	1990
A1-16	Potential	1990	1990
A1-17	Low	1990	1975
A1-18	Potential	1990	1975

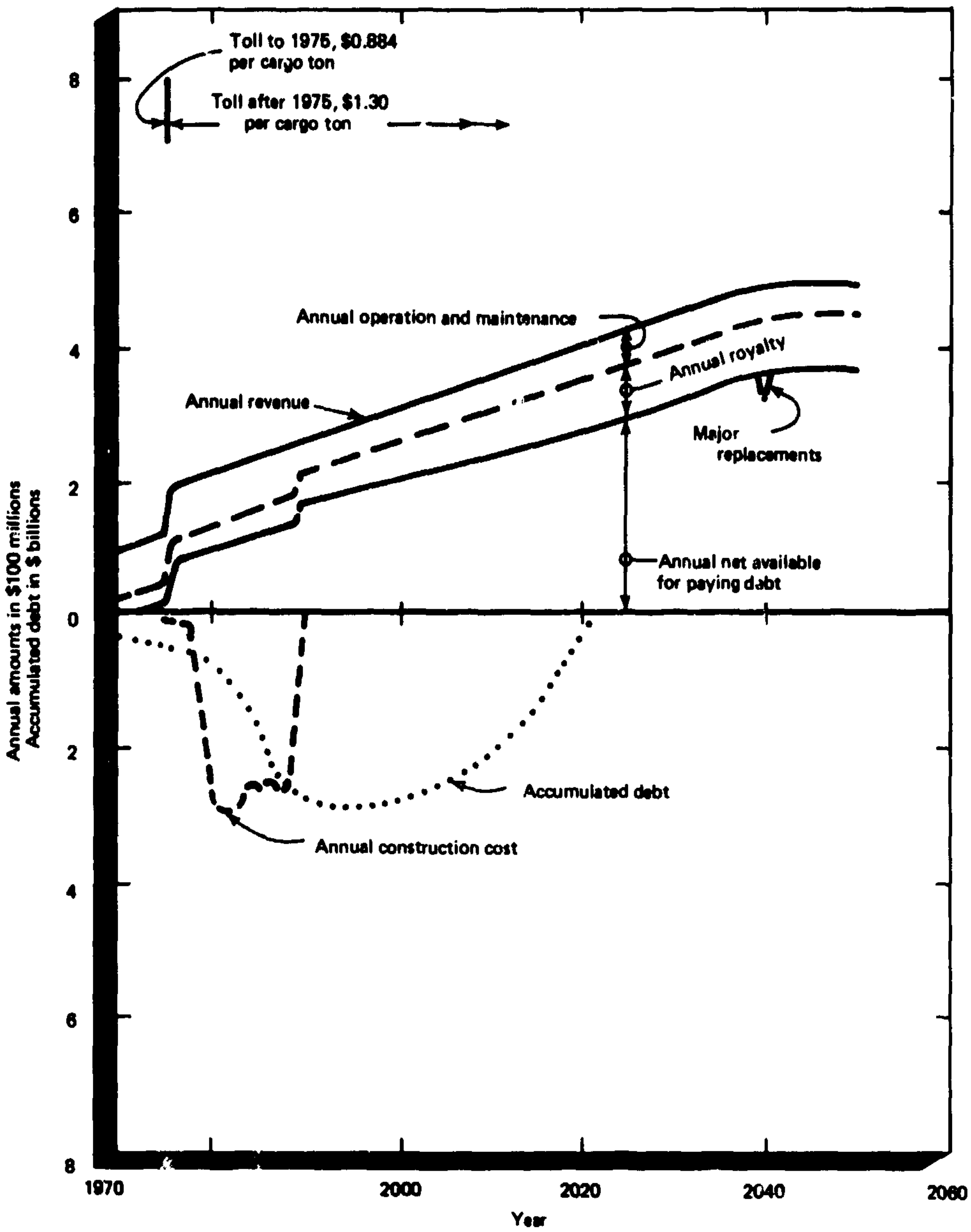


NOTES:

1. Construction cost is $2.88 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. New canal opens in 1990.
5. Payout is in 2007 because of high tolls.
6. Potential tonnage and 25% mix used.
7. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
8. Panama Canal assumed on standby for ten years and then in mothballs.

ROUTE 10 CASH FLOW ANALYSIS

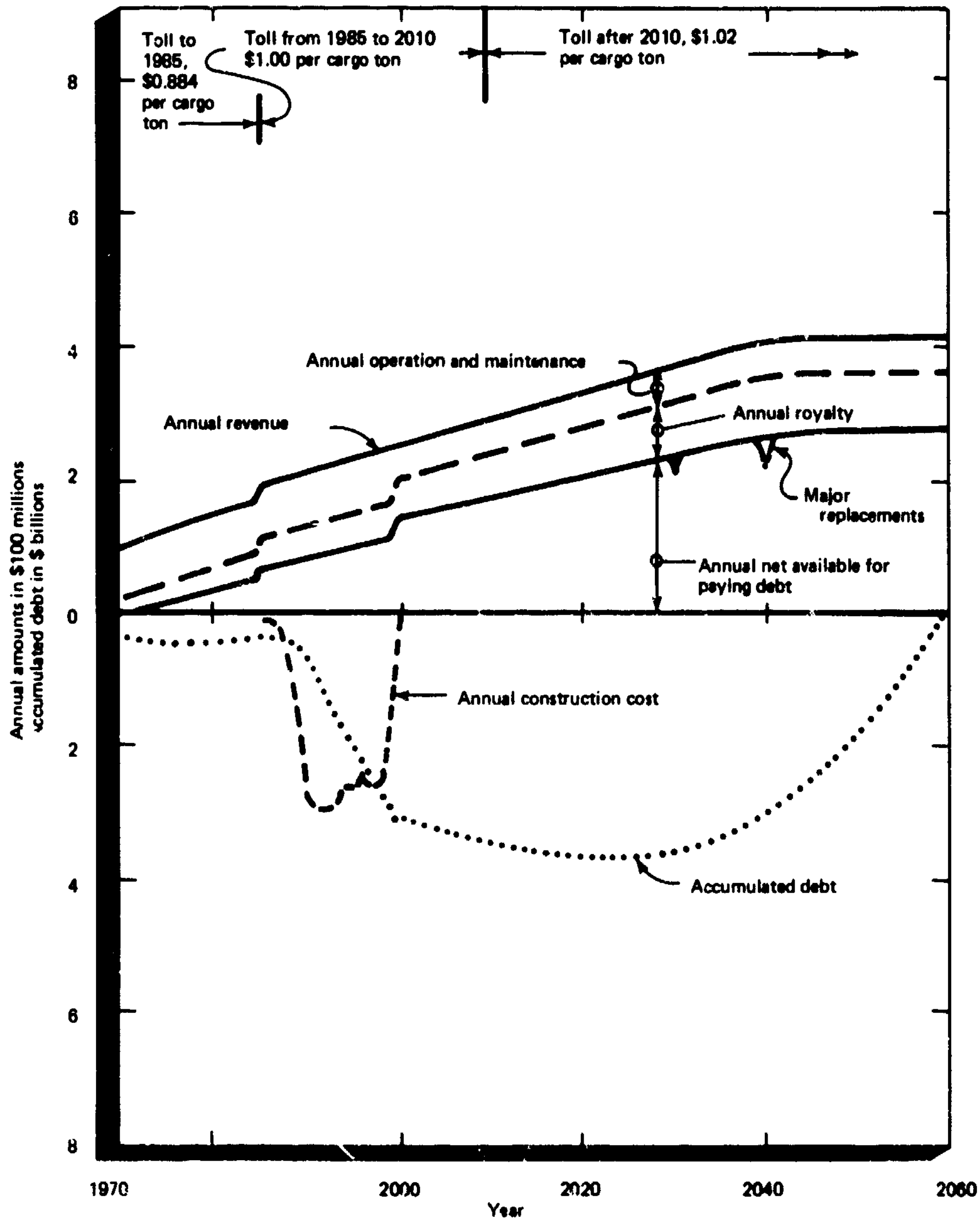
FIGURE A1-8



NOTES:
1. Construction cost is $2.88 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. New canal opens in 1990.
5. Payout is in 2021 because of high tolls.
6. Low tonnage and 46% mix used.
7. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
8. Panama Canal assumed on standby for ten years and then in mothballs.

ROUTE 10 CASH FLOW ANALYSIS

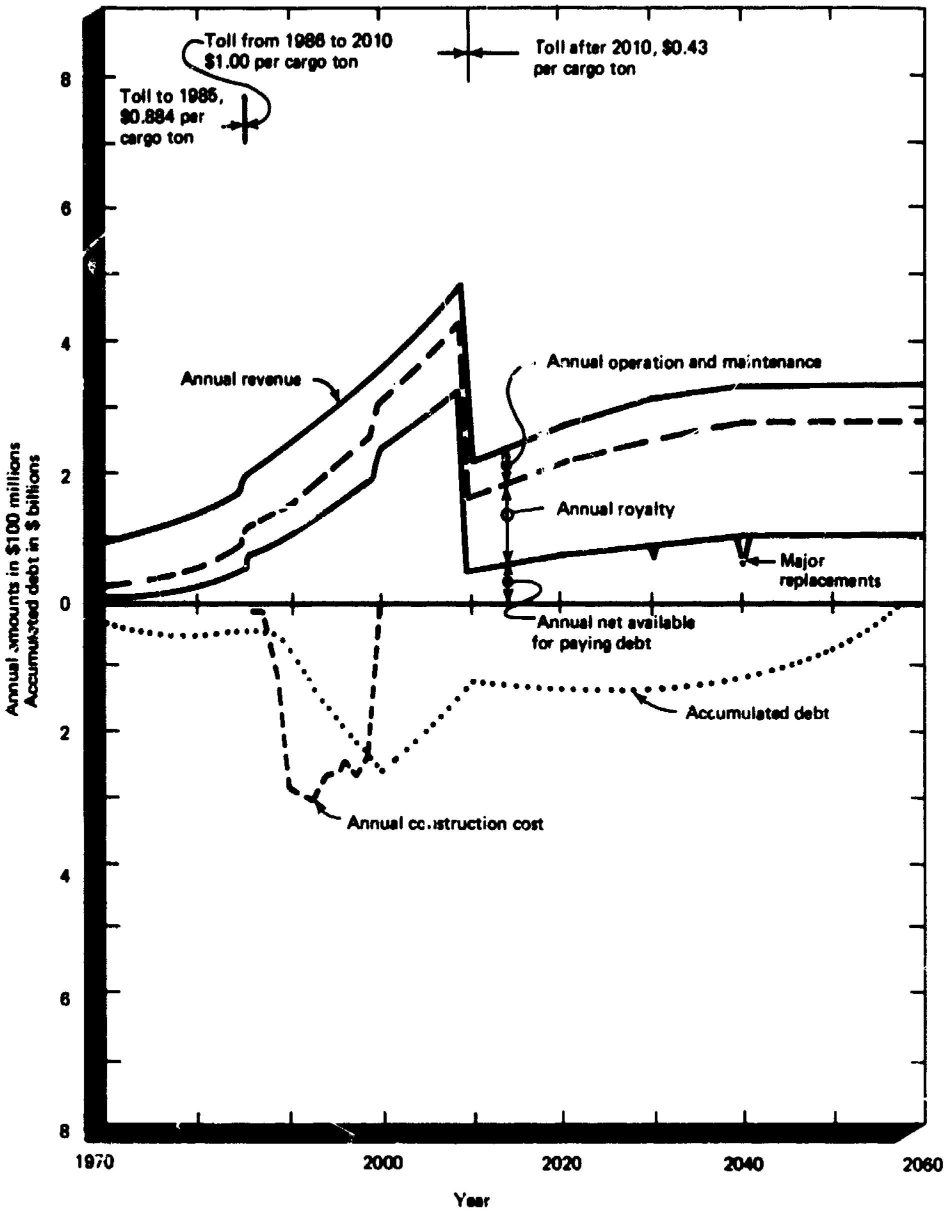
FIGURE A1-9



NOTES:
1. Construction cost is $2.88 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. New canal opens in 2000 for payout in 2060.
5. Low tonnage projection and 46% mix used.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Panama Canal kept on a standby for ten years and then in mothballs.

ROUTE 10 CASH FLOW ANALYSIS

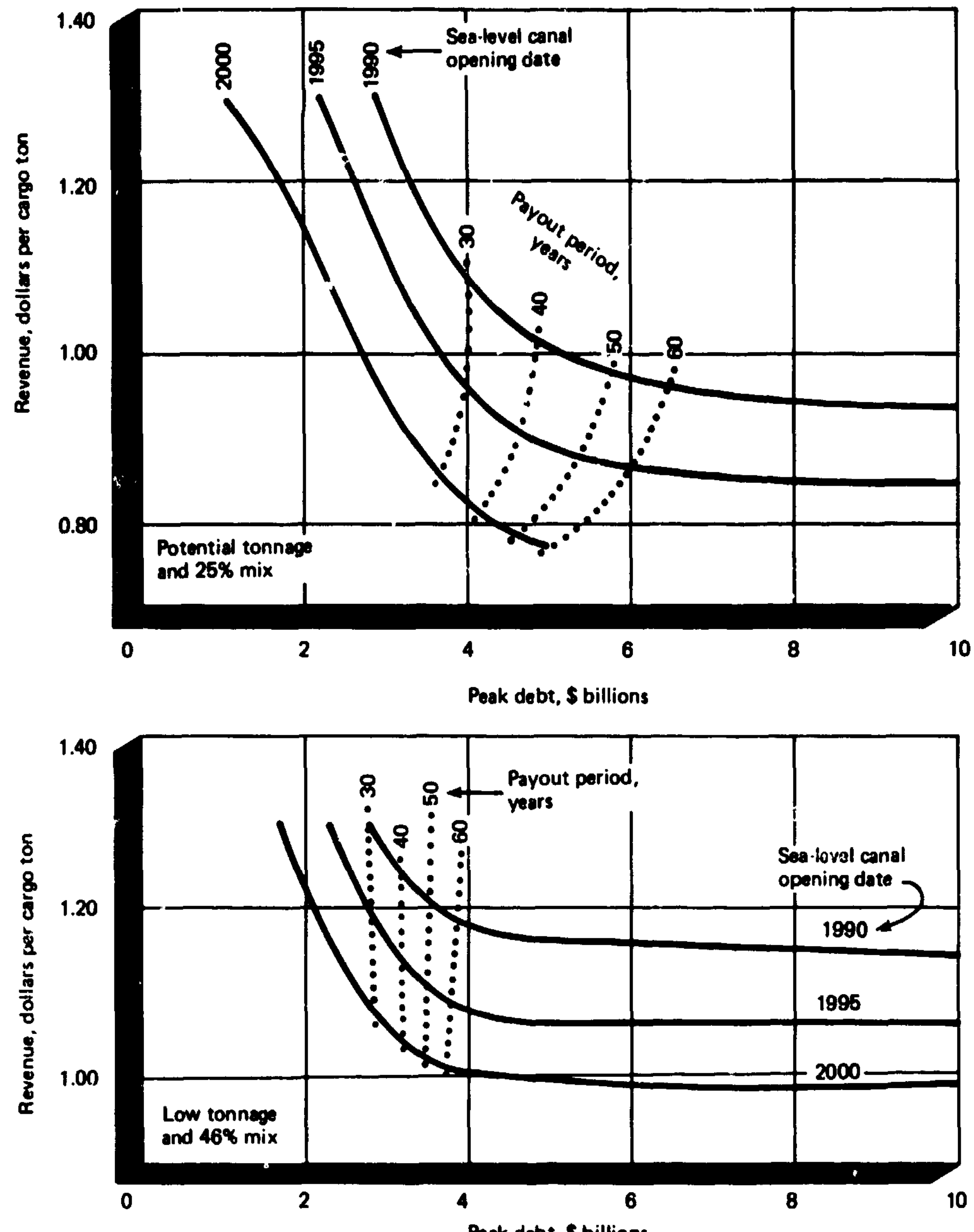
FIGURE A1-10



NOTES:
1. Construction cost is $2.88 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. New canal opens in 2000 for payout in 2060.
5. Potential tonnage projection and 25% mix used.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Panama Canal kept on standby for ten years, and then in mothballs.

ROUTE 10 CASH FLOW ANALYSIS

FIGURE A1-11

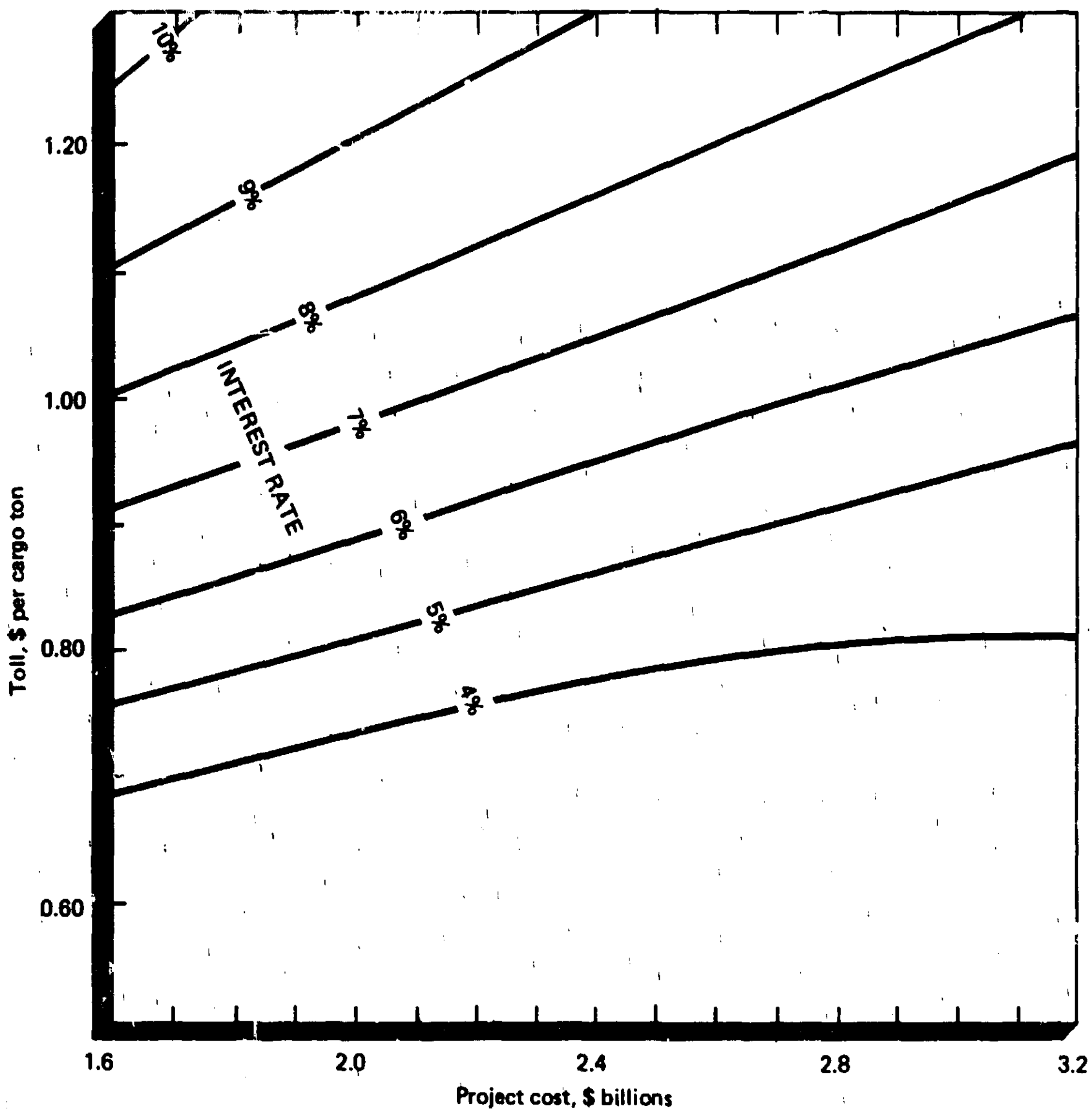


NOTES:

1. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
2. PCC revenue of $0.884 per cargo ton was assumed until canal construction is started.
3. Interest rate is 6%.
4. Panama Canal assumed on standby for ten years, and then in mothballs.
5. Route 10 cost is $2.88 billion.
6. Royalty reaches $0.22 in 1976.

ROUTE 10 ANALYSIS OF PEAK DEBT

FIGURE A1-12

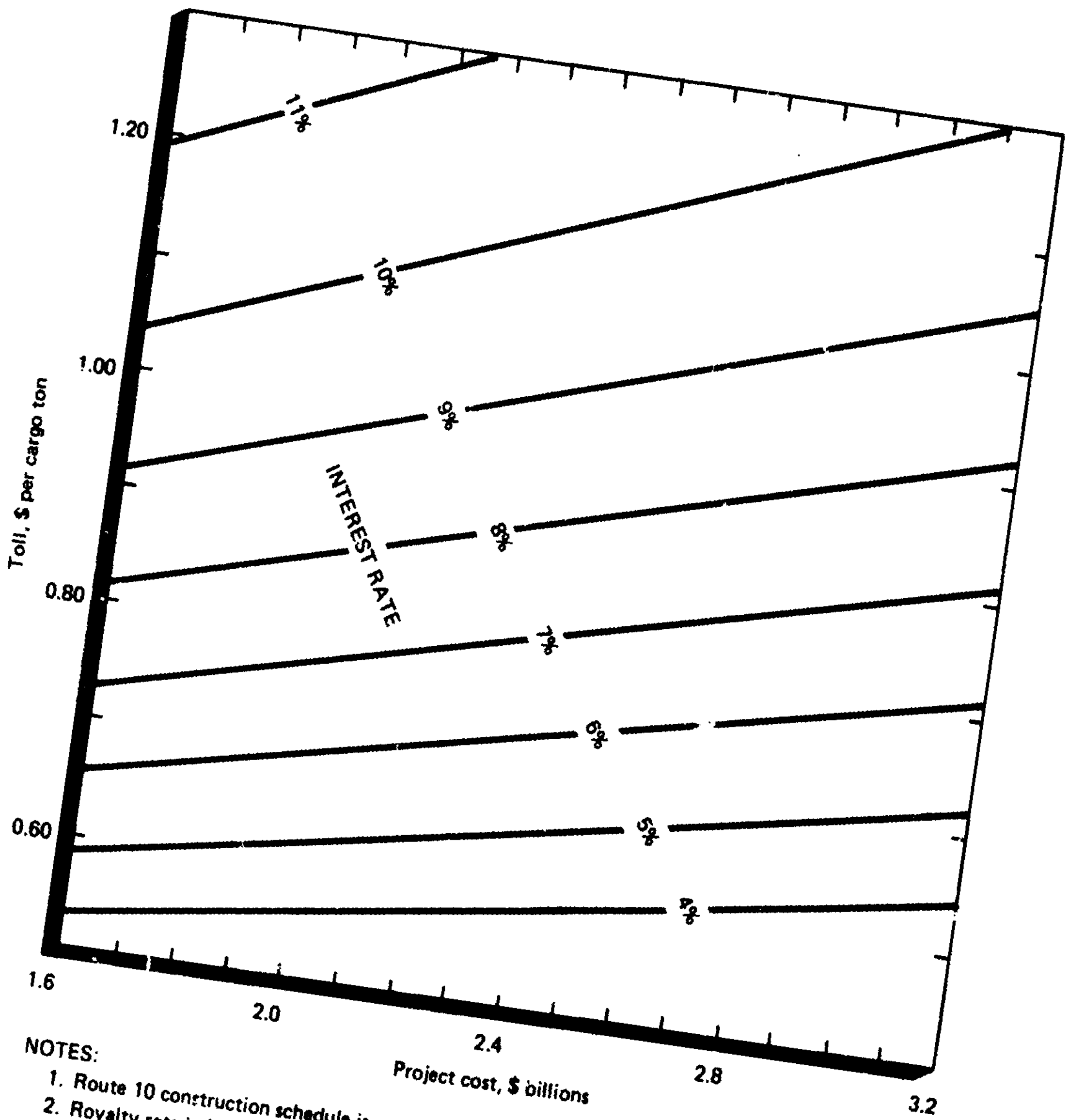


NOTES:

1. Route 10 construction schedule is assumed.
2. Royalty rate is $0.22 per cargo ton.
3. Sea-level canal is opened in 2000.
4. Payout is in 2060.
5. Low tonnage and 46% mix are assumed.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Toll of $0.884 per cargo ton assumed until sea-level canal construction is started.
8. Panama Canal assumed on standby for 10 years and then in mothballs.

ROUTE 10 SENSITIVITY OF TOLL TO PROJECT COST

FIGURE A1-13

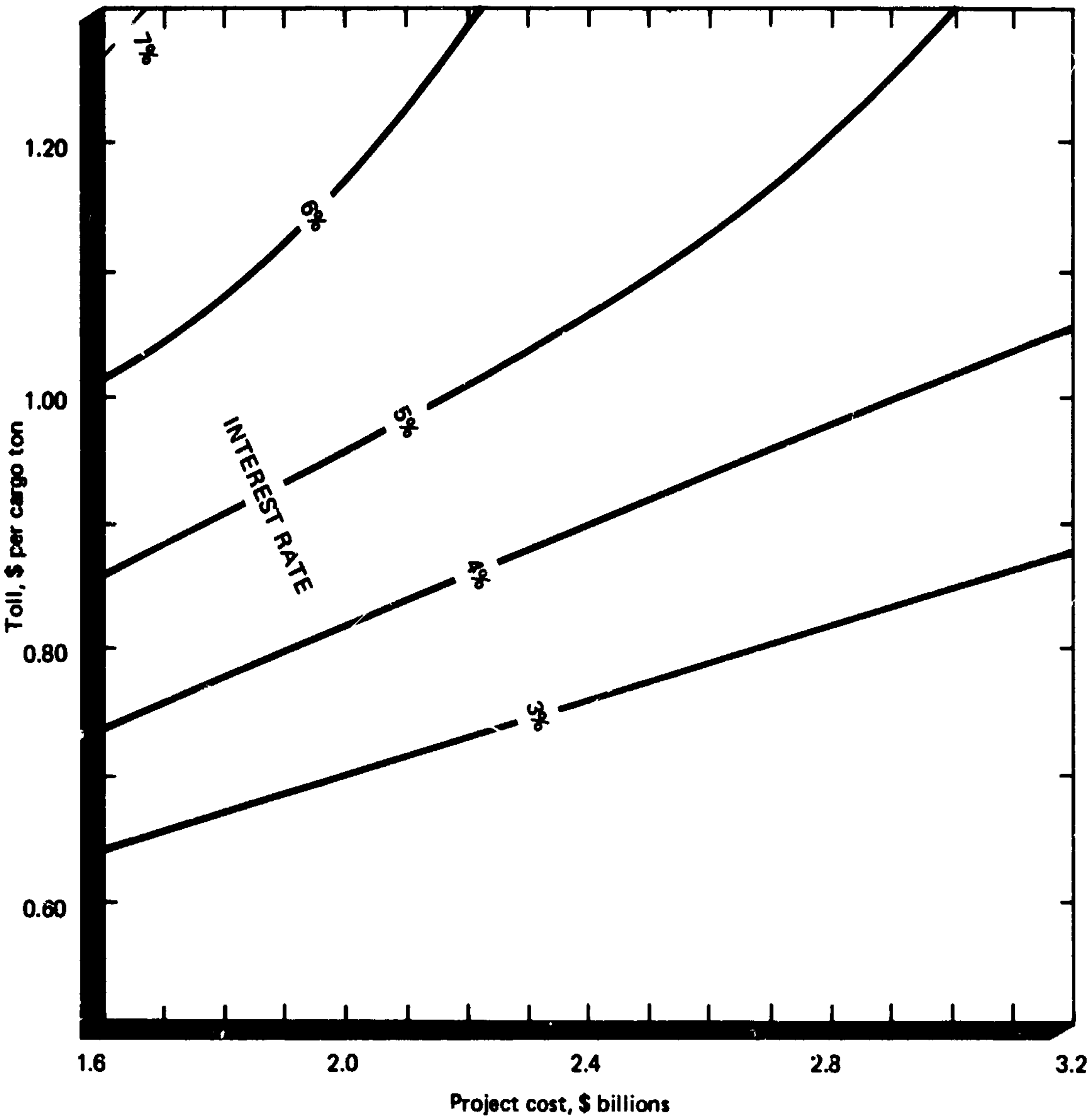


NOTES:

1. Route 10 construction schedule is assumed.
2. Royalty rate is $0.22 per cargo ton.
3. Sea-level canal is opened in 2000.
4. Payout is in 2060.
5. Potential tonnage and 25% mix are assumed.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Toll of $0.884 per cargo ton assumed until sea-level canal construction is started.
8. Panama Canal assumed on standby for ten years and then in mothballs.

ROUTE 10 SENSITIVITY OF TOLL TO PROJECT COST

FIGURE A1-14

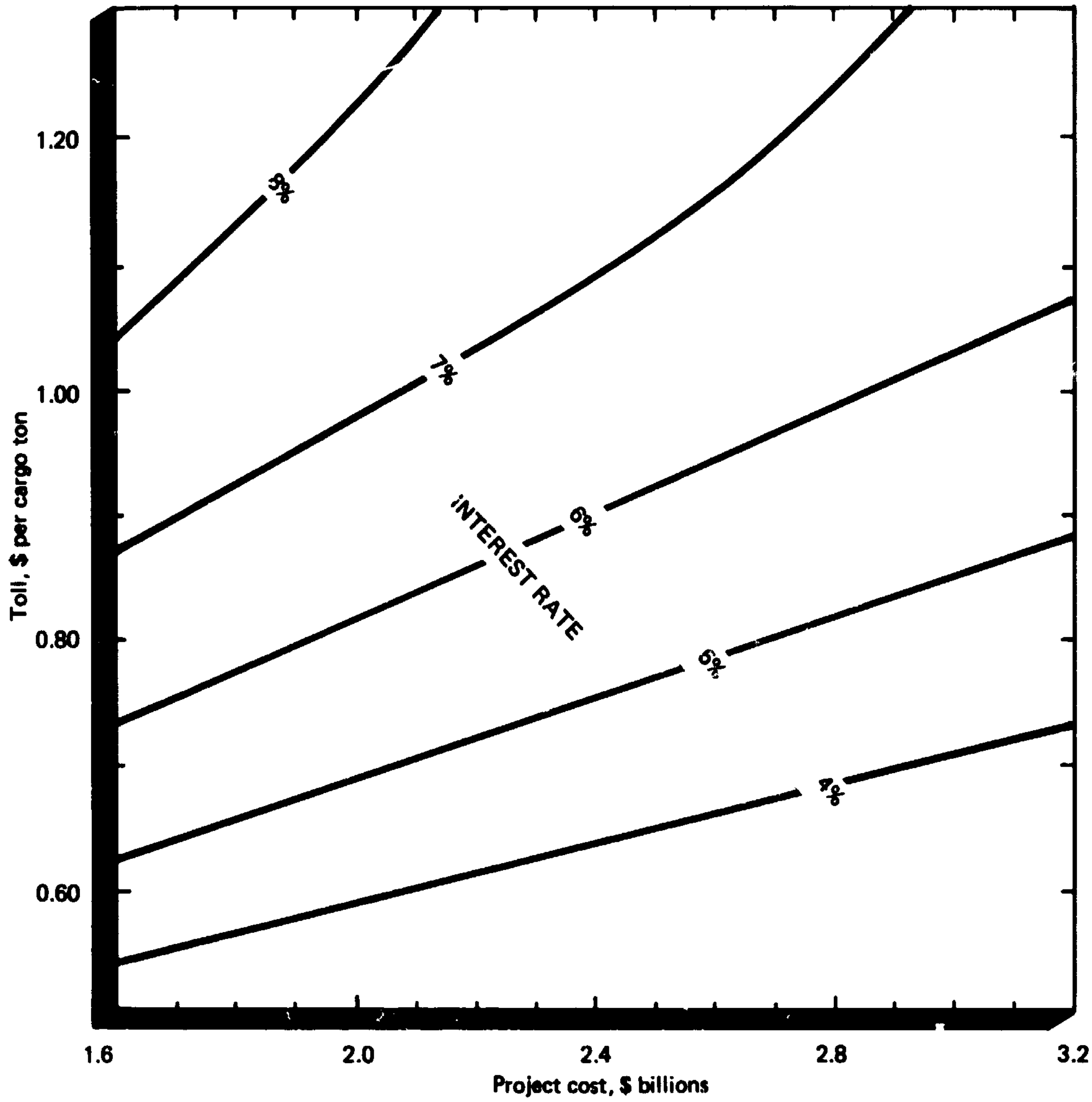


NOTES:

1. Route 10 construction schedule is assumed.
2. Royalty rate is $0.22 per cargo ton.
3. Sea-level canal is opened in 1990.
4. Payout is in 2050.
5. Low tonnage and 46% mix are assumed.
6. Canal financing assumed an extension of that of the Panama Canal with a debt of $317 million in 1970.
7. Toll of $0.884 per cargo ton assumed until sea-level canal opens.
8. Panama Canal assumed on standby for 10 years and in mothballs thereafter.

ROUTE 10 SENSITIVITY OF TOLL TO PROJECT COST

FIGURE A1-15

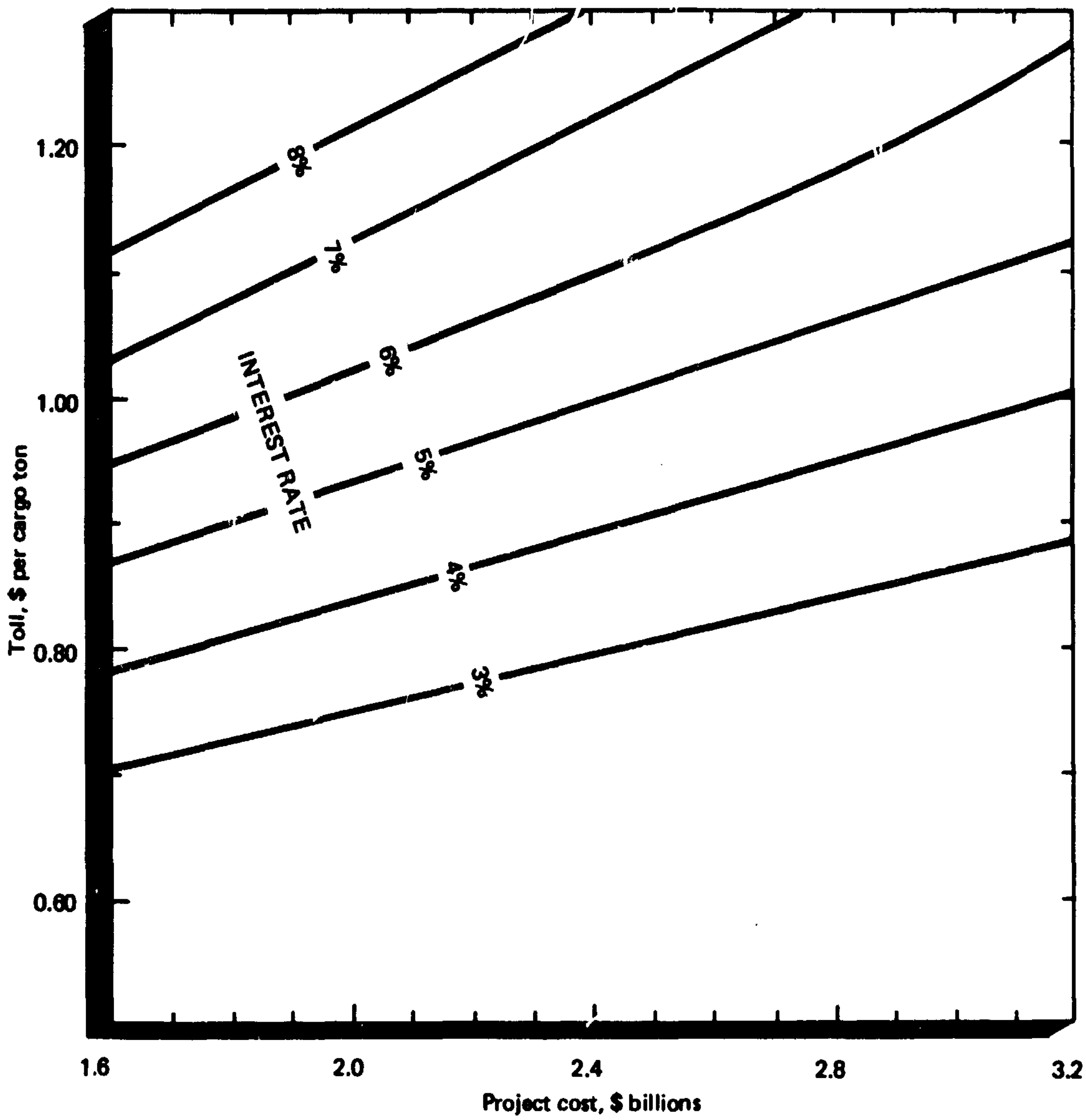


NOTES:

1. Route 10 construction schedule is assumed.
2. Royalty rate is $0.22 per cargo ton.
3. Sea-level canal is opened in 1990.
4. Payout is in 2050.
5. Potential tonnage and 25% mix are assumed.
6. Canal financing assumed an extension of that of the Panama Canal with a debt of $317 million in 1970.
7. Tolls of $0.884 per cargo ton assumed until sea-level canal opens.
8. Panama Canal assumed on standby for ten years and in mothballs thereafter.

ROUTE 10 SENSITIVITY OF TOLL TO PROJECT COST

FIGURE A1-16

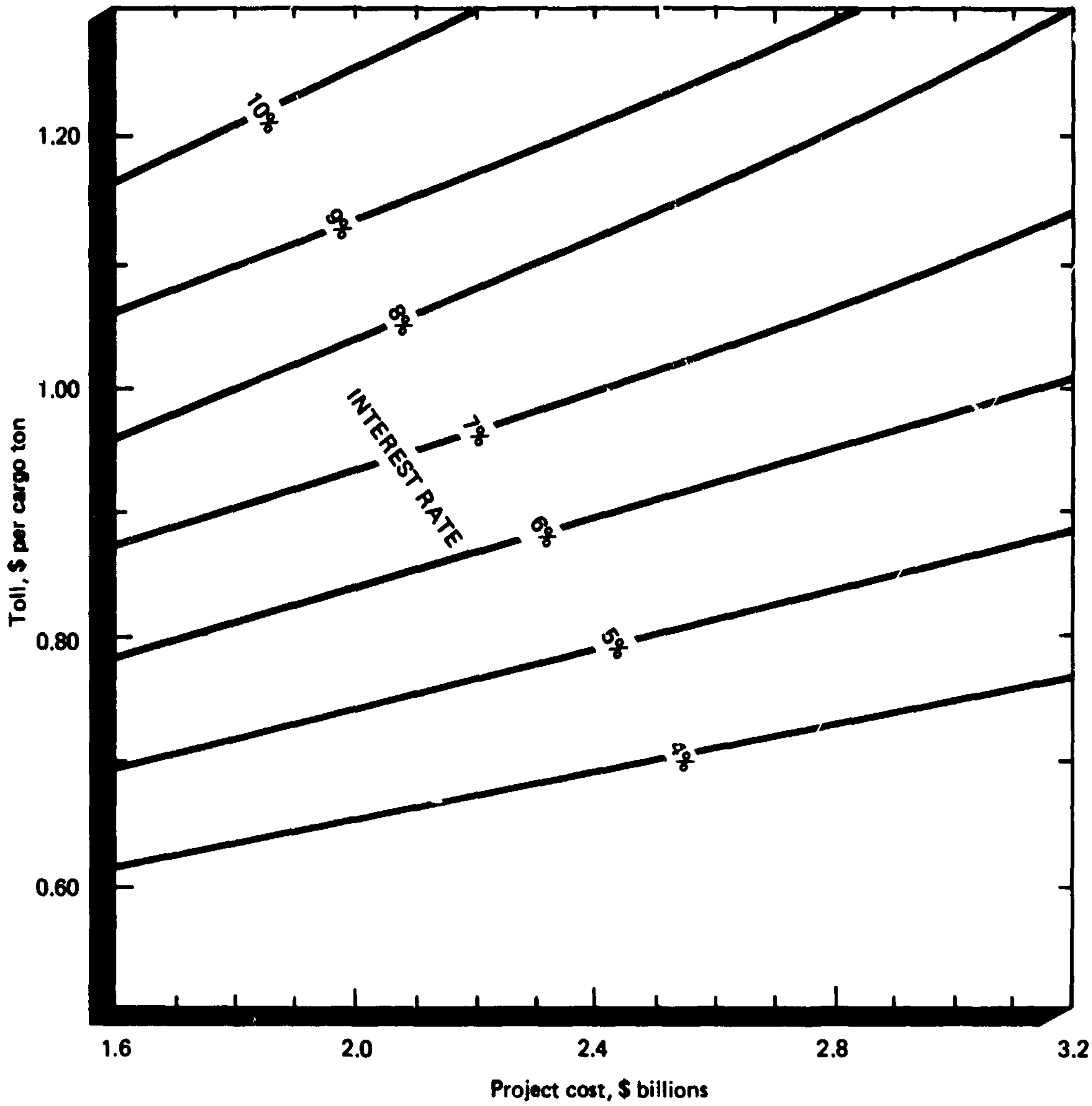


NOTES:

1 Route 10 construction schedule is assumed.
2. Royalty reaches $0.22 per cargo ton in 1976.
3. Sea-level canal is opened in 1990.
4. Payout is in 2050.
5. Low tonnage and 46% mix are assumed.
6. Canal financing assumed an extension of that of the Panama Canal with a 1970 debt of $317 million.
7. Toll of $0.884 per cargo ton assumed until sea-level canal construction is started.
8. Panama Canal assumed on standby for ten years and then in mothballs.

ROUTE 10 SENSITIVITY OF TOLL TO PROJECT COST

FIGURE A1-17



NOTES:

1. Route 10 construction schedule is assumed.
2. Royalty reaches $0.22 in 1976.
3. Sea-level canal opens in 1990.
4. Payout is in 2050.
5. Potential tonnage and 25% mix are assumed.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Tolls of $0.884 per cargo ton assumed until sea-level canal construction is started.
8. Panama Canal assumed on standby for ten years and then in mothballs.

ROUTE 10 SENSITIVITY OF TOLL TO PROJECT COST
FIGURE A1-18

passes through $2.88 billion as measured on the horizontal scale at a toll rate of $1.02 per cargo ton, as measured on the vertical scale). If reimbursable costs were determined to be one-half billion dollars less for some reason, the comparable toll would be $0.95 per cargo ton. (The line identified as 6% passes through $2.38 billion as measured on the horizontal scale at a toll rate of $0.95 per cargo ton, as measured on the vertical scale).

Figures A1-13 and the others may also be used to approximate the effect of royalty rates differing from the $0.22 per cargo ton used in the analyses. For example, tolls of $0.83 per cargo ton, out of which royalties of $0.17 per cargo ton are paid, would have the same financial effect as tolls of $0.88 per cargo ton as read on the figure from which royalties of $0.22 per cargo ton are assumed to be paid.

Recoverable Construction Costs, Route 10, Panama Canal Toll Levels

Figures A1-13 through A1-18 can be used to determine the approximate portion of Route 10 construction costs which could be recovered at various interest rates and toll levels. The amounts which could be recovered using current Panama Canal toll rates are examined below on the basis that the current tolls have not been changed for a long time, and may also be resistant to future change. The values in the following Table A1-8 are taken from Figures A1-13 and A1-14.

TABLE A1-8
ROUTE 10
Recoverable Construction Costs at Current Panama Canal Toll Rates

Interest Rate	Construction Cost in Billions Recoverable	Unrecoverable
"Potential" tonnage projection[1]		
6%	$2.9	$0.0
7%	2.1	0.8
7.6%	1.6[2]	1.3
"Low" tonnage projection[3]		
6%	2.0	0.9
6.7%	1.6[2]	1.3

[1] Based on a toll rate of $0.777 per cargo ton on the vertical scale of Figure A1-14; corresponds to the 25% freighter cargo mix.
[2] Lower limit of reimbursable costs examined in the sensitivity studies.
[3] Based on a toll rate of $0.884 per cargo ton on the vertical scale of Figure A1-13; corresponds to the 48% freighter cargo mix.

Sensitivity of Tolls to Transit Capacity, Route 10

The Engineering Feasibility Study indicates that the capacity of Route 10 is 38,000 transits a year unless operational methods not now considered safe can be adopted after

experience has been gained in operating the sea-level canal. The 38,000 transit capacity would be exceeded in about year 2025 if the "potential" tonnage growth and 25% freighter cargo mix were realized. Studies were undertaken to determine the effect on self-liquidating tolls if transit capacity were found to be less than the 39,300 transits a year projected for the period after 2040 with the "potential" tonnage projection. The results of the study are shown graphically in Figure A1-19 and in tabular form in Table A1-9. The effect on self-liquidating tolls is small.

TABLE A1-9
ROUTE 10
Effect of Transit Capacity on Self-liquidating Tolls

Capacity, Transits per Year	Self-liquidating Toll per Cargo Ton[1]
39,300 and above	$0.957
38,000	0.960
36,000	0.966
34,000	0.974

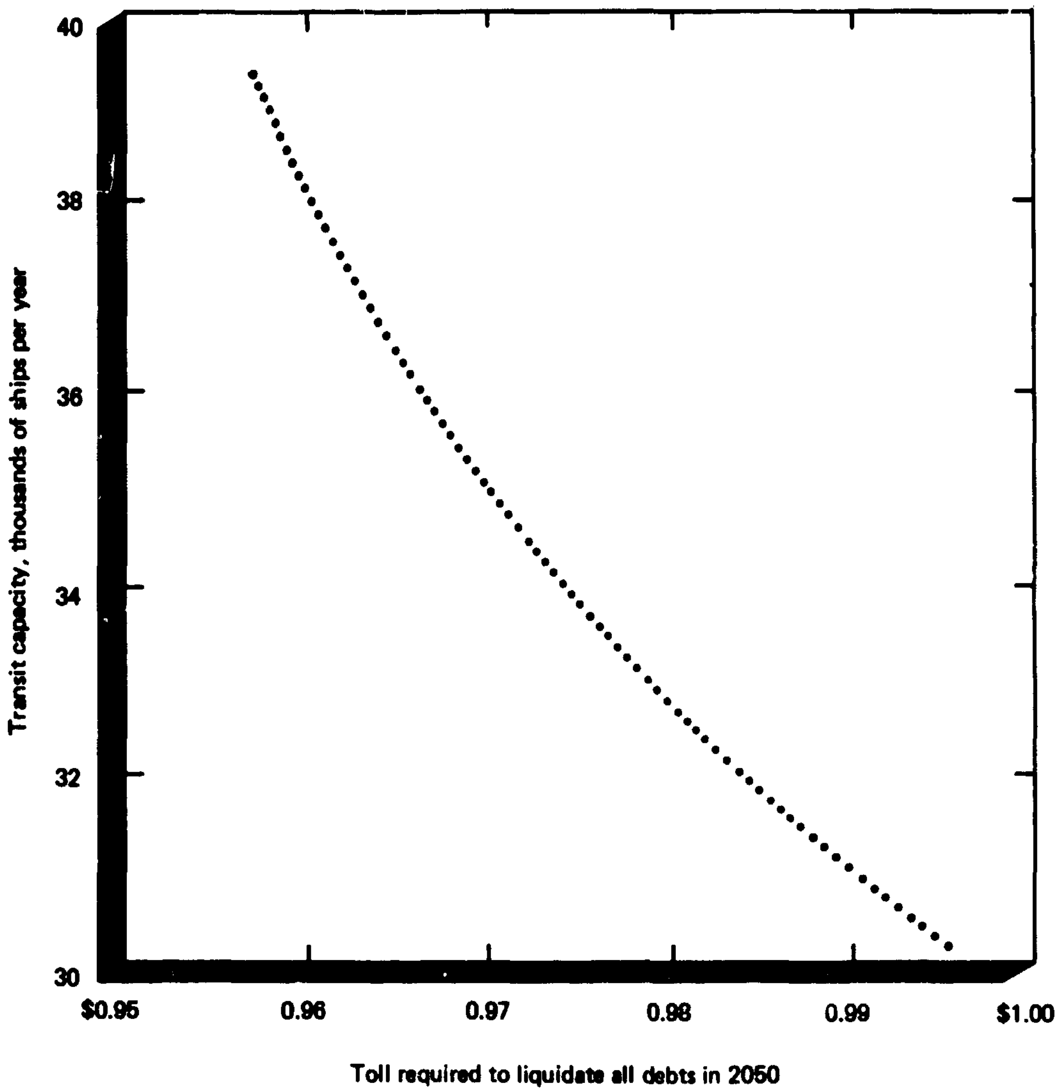
[1] Route 10 opens in 1990 and pays out in 2050. Interest 6%. Potential tonnage and 25% mix. Tolls change from assumed $0.884 in 1975 at the start of construction.

If canal operating experience shows that additional transit capacity cannot be secured any other way, a bypass could be provided at a cost of $460 million, after four years of construction. For the "potential" tonnage growth, 25% freighter cargo mix, the bypass should be ready for operation in 2025. Figure A1-20 illustrates the changes in cash flow if (a) tolls were changed in 1975 by the amount necessary to maintain payout date, and (b) tolls were maintained at the former level and payout date were allowed to change. Table A1-10 summarizes the results.

TABLE A1-10
ROUTE 10
Effects of a Bypass

Analysis[1]	Toll per Cargo Ton	Peak Debt, Billions	Year of Payout
Without bypass[2]	$0.957	$6.5	2050
With bypass	0.957	6.7	2055
With bypass	0.963	6.4	2050

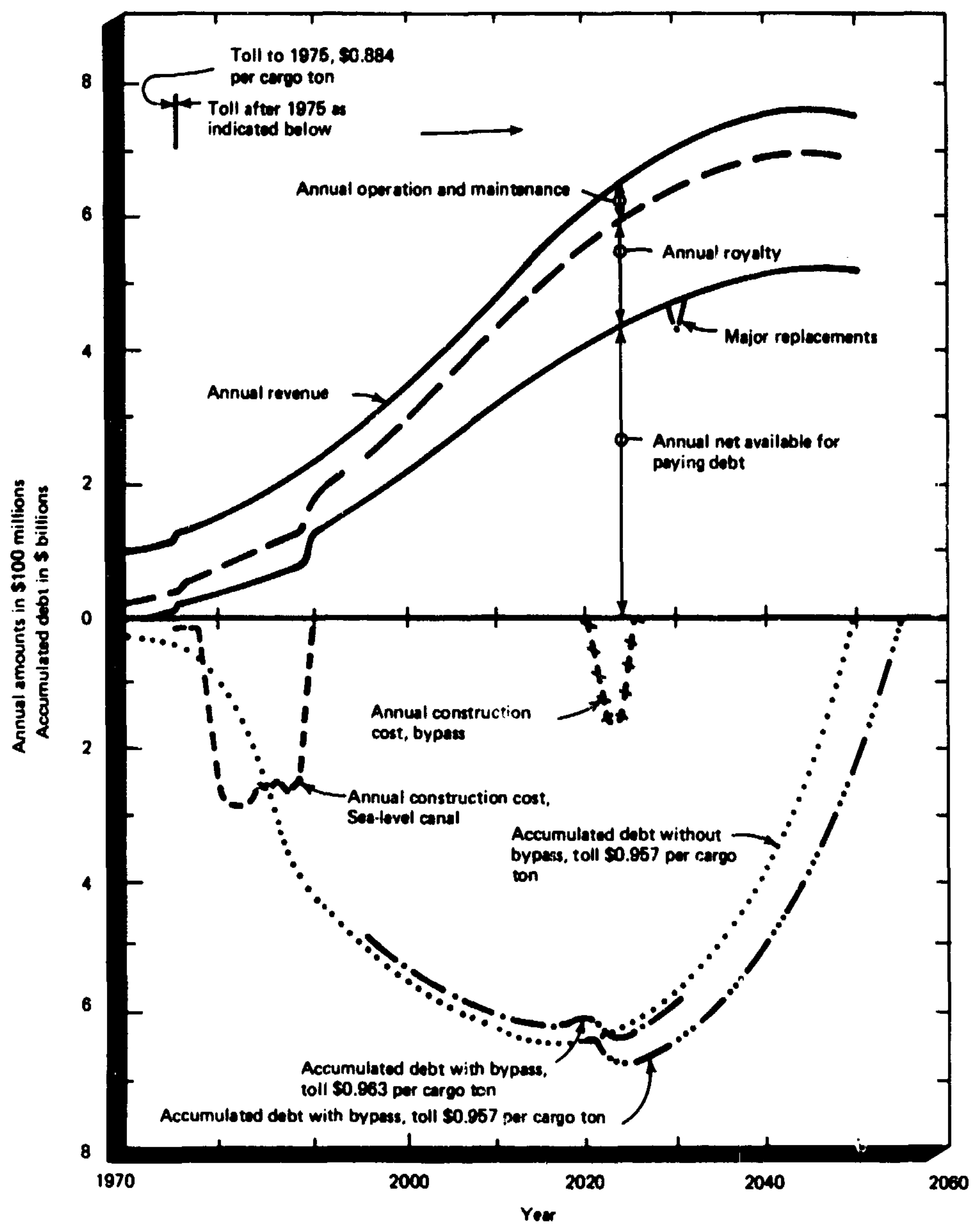
[1] Start Route 10 construction and increase tolls from $0.884 per cargo ton in 1975. Start operation in 1990. Start bypass operation in 2025. 6% interest. Potential tonnage.
[2] Assuming Route 10 without a bypass has a capacity exceeding 39,300 transits a year.



NOTES:
1. Construction cost is $2.88 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 in 1976.
4. New canal opens in 1990 for payout in 2050.
5. Potential tonnage and 25% mix used.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Panama Canal kept on standby for 10 years and then in mothballs.

ROUTE 10 SENSITIVITY OF TOLLS TO TRANSIT CAPACITY

FIGURE A1-19



NOTES:
1. Construction cost $2.88 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. New canal opens in 1990 for payout in 2050.
5. Potential tonnage projection and 25% mix used.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Panama Canal kept on standby for ten years and then in mothballs.
8. Cost of bypass $460 million.

ROUTE 10 CASH FLOW ANALYSIS
EFFECTS OF A BYPASS

FIGURE A1-20

If tolls were set according to the "low" tonnage projection, the higher toll rates would automatically provide the needed funds for construction of additional facilities should rapid growth of traffic make them necessary. The additional funds available from this procedure would exceed the amounts shown to be necessary by the preceding analysis.

The Panama Canal presents an alternative method for providing additional transit capacity if needed. The effect on tolls would probably be less than discussed above for the bypass case.

Route 14S

Figures A1-21 and A1-22 show the influence of canal opening date on tolls per cargo ton at various interest rates. The former figure assumes tolls to be changed when Route 14S is opened for service, and the latter, when construction is started. The curves show the same characteristics as the curves for Route 10, i.e., with self-liquidating tolls greater than $0.884 per cargo ton, lower tolls will result with the early toll rate change date. For example, with an early toll rate change, an in-service date of 2000, "low" tonnage and 6% interest, self-liquidating toll rates would amount to about $1.09 per cargo ton. (See Figure A1-22) With the late toll change date the required tolls would be more than the $1.30 per cargo ton used as the upper limit to tolls in these studies. (See Figure A1-21)

The greater cost and longer construction period of Route 14S would require a higher toll and result in a greater peak debt than Route 10 under the same conditions. Figure A1-23 shows cash flows for Route 14S under the same general conditions as Figure A1-4 for Route 10. The two figures are compared in Table A1-11.

TABLE A1-11

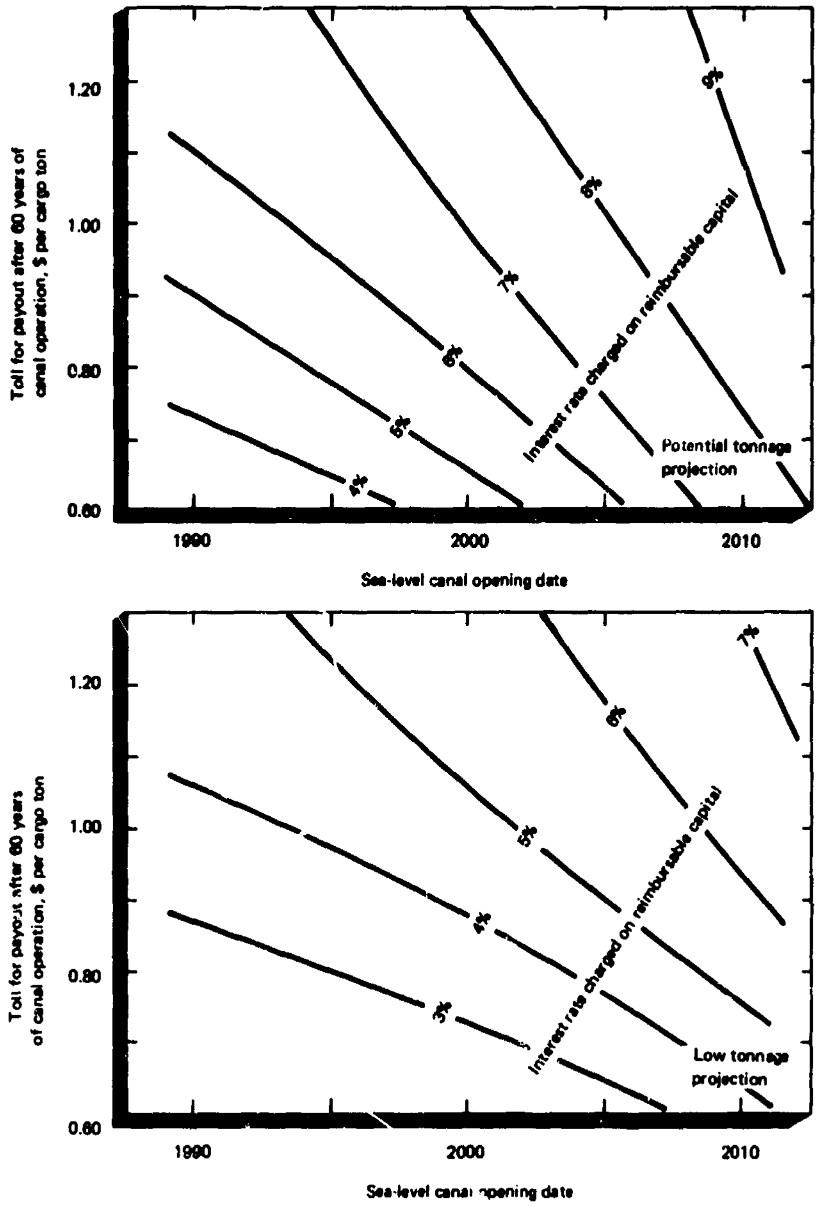
Comparison of Routes 10 and 14S

Route	10	14S
Cost, billions	$2.88	$3.04
Construction period, years	14	16
Self-liquidating toll, per cargo ton[1]	$1.00	$1.10
Peak debt, billions	$6.8	$7.9

[1] Start operation and change tolls from $0.884 in 1990. Interest 6%. "Potential" tonnage.

Route 15

Figures A1-24 and A1-25 show the influence of canal opening date on toll per cargo ton at various interest rates. The former assumes toll rates to be changed when the deep draft locks are opened for service, and the latter, when construction of the locks is started. The curves show the same general characteristics as similar curves for Routes 10 and 14S, i.e., with self-liquidating tolls greater than $0.884 per cargo ton, lower tolls will result with the early toll rate change date. For example, with the early toll rate change date, an in-service date of 1990, "low" tonnage and 6% interest, the self-liquidating toll would amount to

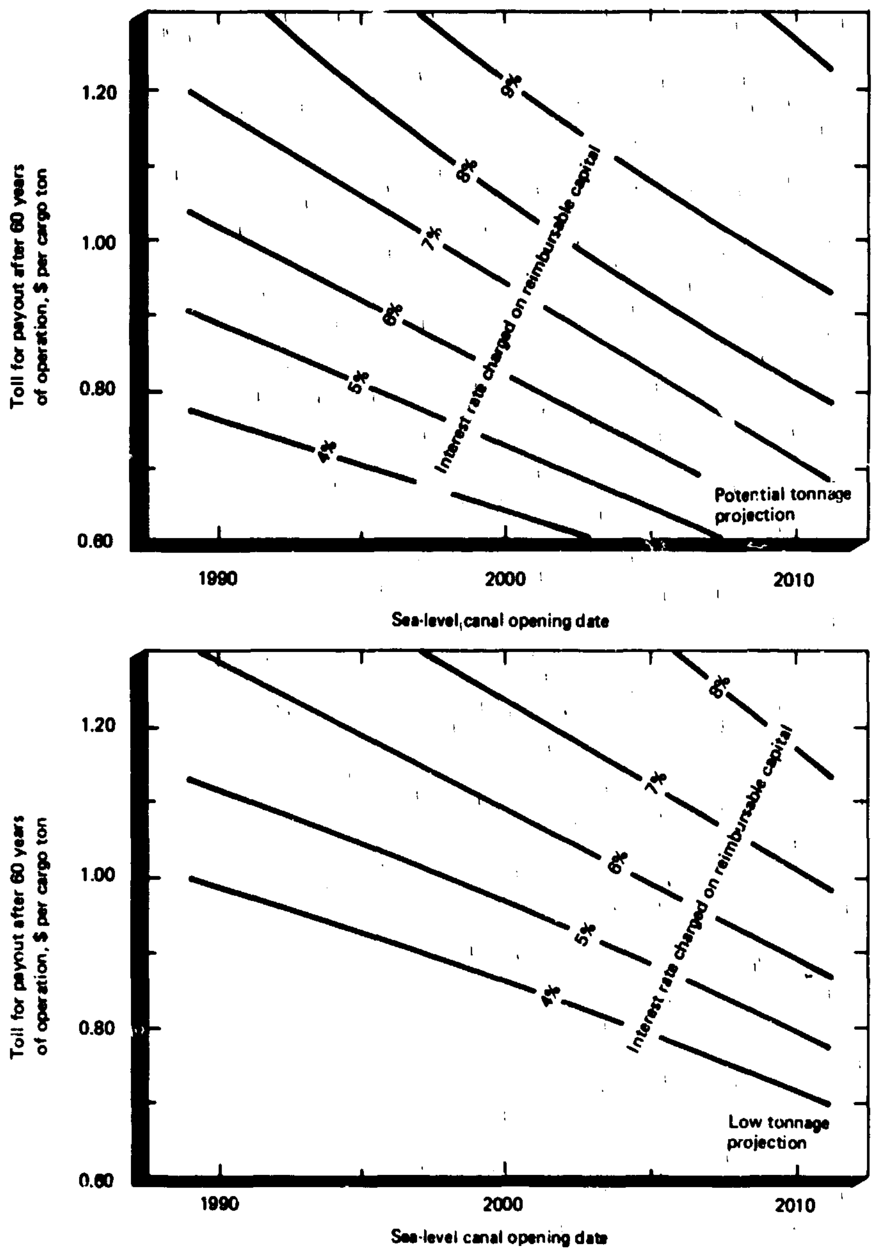


NOTES:

1. Canal financing assumed an extension of that of the Panama Canal with a debt of $317 million in 1970.
2. Toll of $0.884 per cargo ton assumed until sea-level canal opens.
3. Panama Canal assumed abandoned.
4. Route 14S cost is $3.04 billion
5. Royalty reaches $0.22 in 1976.

ROUTE 14S TOLL PER CARGO TON VS. CANAL OPENING DATE

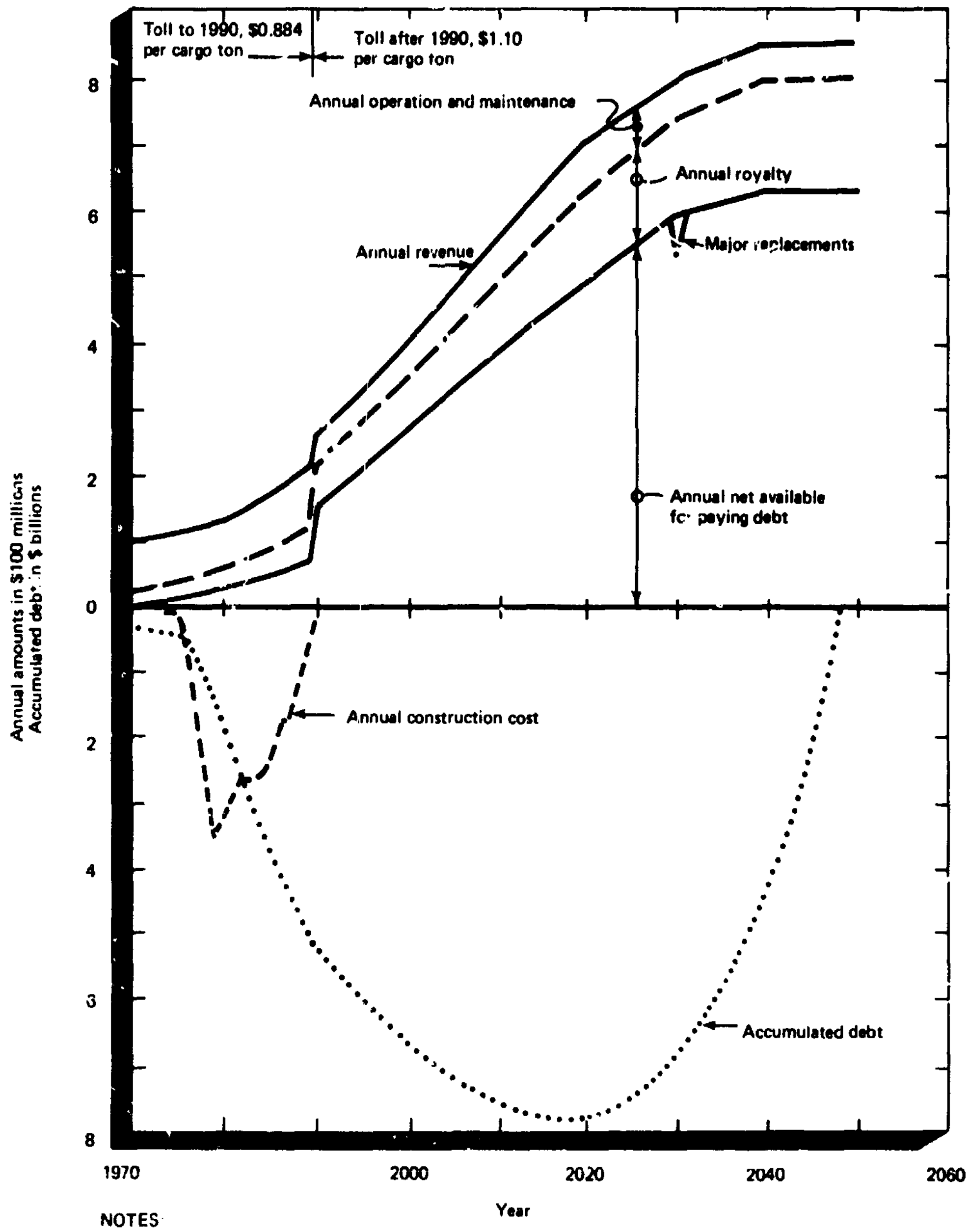
FIGURE A1-21



NOTES:
1. Canal financing assumed an extension of that of the Panama Canal with a debt of $317 million in 1970.
2. Toll of $0.884 per cargo ton assumed until construction of sea-level canal is started.
3. Panama Canal assumed abandoned.
4. Route 14S cost is $3.04 billion.
5. Royalty reaches $0.22 in 1976.

ROUTE 14S TOLL PER CARGO TON VS. CANAL OPENING DATE

FIGURE A1-22

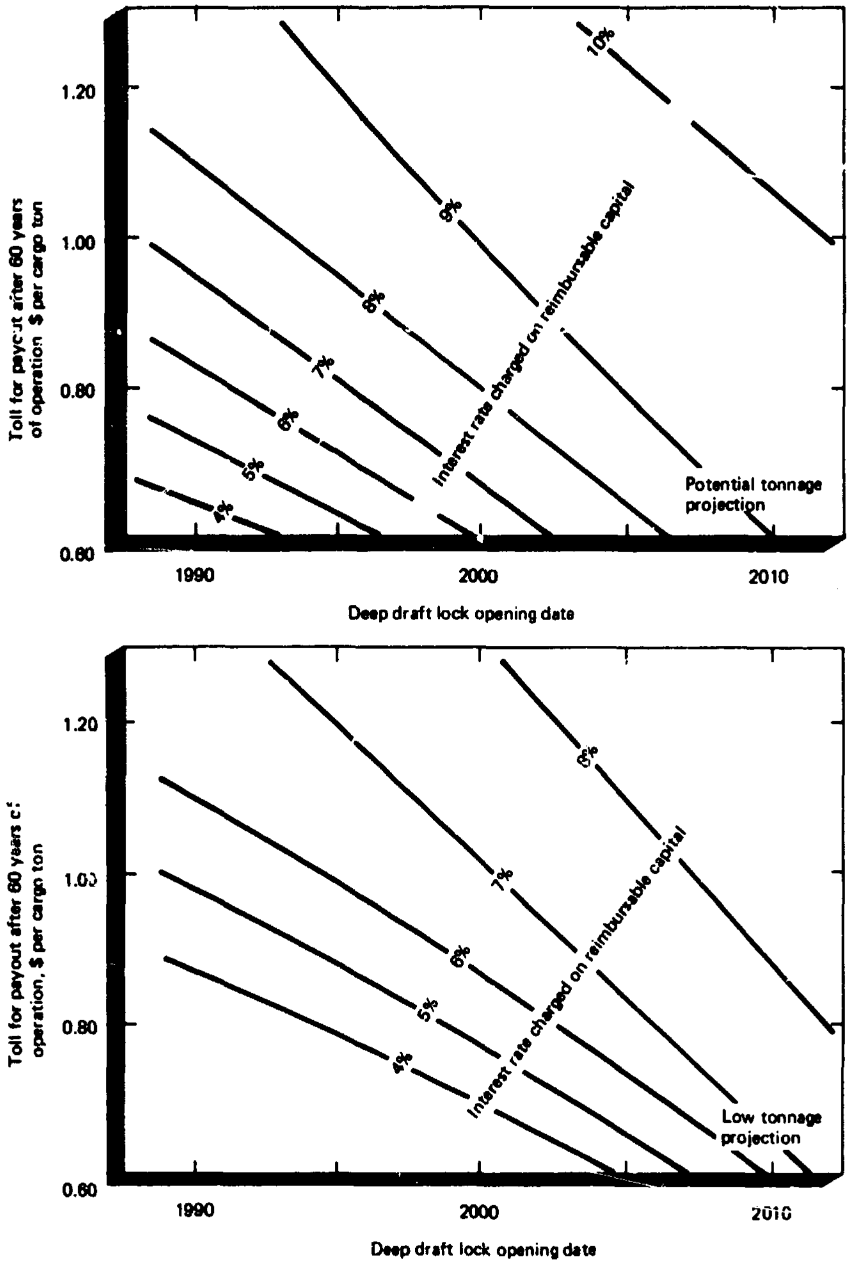


NOTES

1. Construction cost is $3.04 billion.
2. Interest is 6%.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. New canal opens in 1990 for payout in 2050.
5. Potential tonnage and 25% mix used.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Panama Canal locks abandoned with opening of sea-level canal.

ROUTE 14S CASH FLOW ANALYSIS

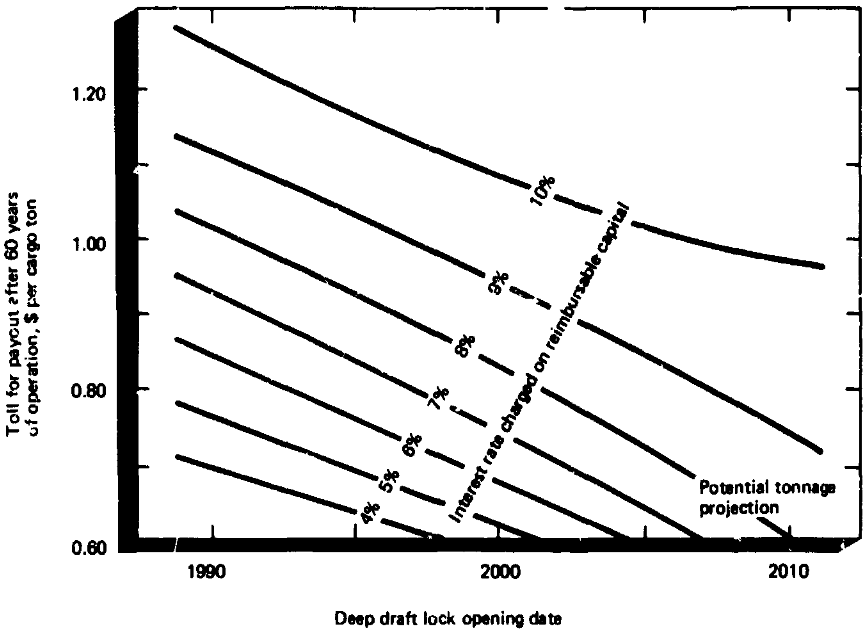
FIGURE A1-23

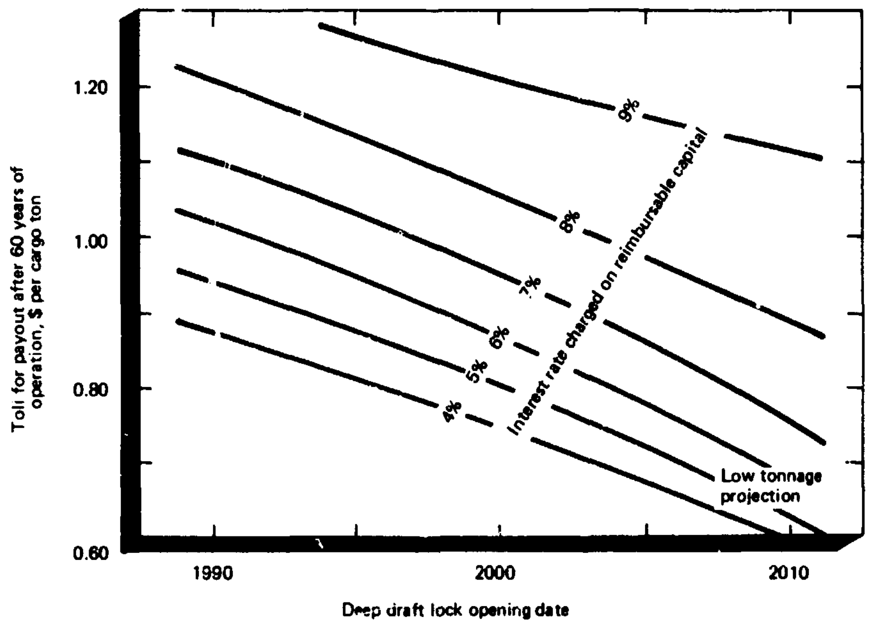


NOTES:
1. Financing of deep draft locks assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
2. Toll of $0.884 per cargo ton assumed until deep draft lock opens.
3. Cost of deep draft locks is $1.53 billion.
4. Royalty reaches $0.22 per cargo ton in 1976.

ROUTE 15 TOLL PER CARGO TON VS. CANAL OPENING DATE

FIGURE A1-24





NOTES:
1. Financing of deep draft locks assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
2. Toll of $0.884 per cargo ton assumed until deep draft lock construction is started.
3. Cost of deep draft locks is $1.53 billion.
4. Royalty reaches $0.22 per cargo ton in 1976.

ROUTE 15 TOLL PER CARGO TON VS. CANAL OPENING DATE

FIGURE A1-25

$1.02 (Figure A1-25). With the late toll rate change date (Figure A1-24), the required toll would be $1.10.

Figure A1-26 shows the cash flows for the same conditions as shown on Figure A1-4 for Route 10 and A1-23 for Route 14S. Figure A1-27 is a modification of the figure preceding it in that the present locks are assumed to require replacement by 2000. This date probably represents the earliest date at which replacement would be required, if at all. The 35,000 annual transit capacity of Route 15 is indicated on Figures A1-26 and A1-27 by the break in the revenue curve at about the year 2015.

The lower first cost of Route 15 permits lower tolls and lower peak debts, even if replacement of the present Panama Canal locks were required by 2000. The sea-level canal options and the lock canal options are compared in Table A1-12.

TABLE A1-12

Comparison of Sea-Level and Lock Canal Options

Route	Sea-Level Canals		Lock Canals	
	10	14S	15	15
Panama Canal locks replaced	[1]	[1]	No	Yes
Cost, billions	$2.88	$3.04	$1.53	$2.33[2]
Self-liquidating toll[3] per cargo ton	$1.00	$1.10	$0.83	$0.91
Peak debt	$6.8	$8.9	$3.8	$4.4

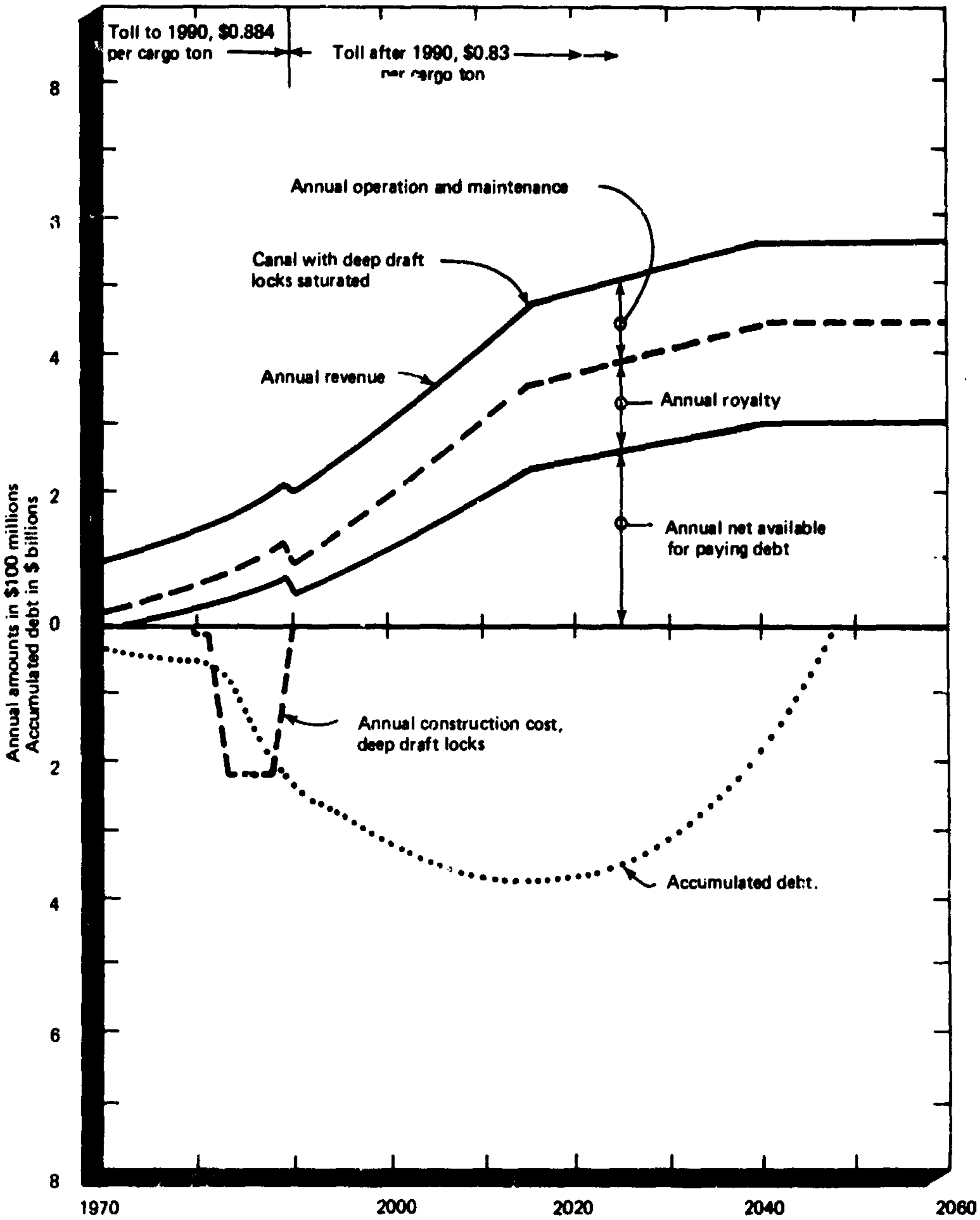
[1] Not applicable.
[2] $1.53 billion for Route 15 construction plus $800 million to replace Panama Canal locks.
[3] Start operations of each option and change tolls from $0.884 in 1990. Interest 6%. Potential tonnage.

Continued Operation of The Panama Canal

Continued use of the present Panama Canal, improved as recommended in the Kearney Report, is a possible alternative to the sea-level canal and lock canal options. Because of its size limitation to 65,000 DWT ships and its capacity limitation of 26,800 transits a year, it is not comparable to the other options under consideration.

The finances of continued operation of the Panama Canal under the Panama Canal Company and including a Canal Zone Government at its present size has been examined using a toll rate of $0.884 per cargo ton for both the "potential" and the "low" tonnage projections, and $0.884 declining to $0.777 per cargo ton in year 2000 for the "potential" tonnage projection.[2] Even under these more costly operating assumptions than were used with the sea-level canal options, the current debt on which the Panama Canal Company pays interest and the cost of the Kearney improvements would be paid off at a relatively early

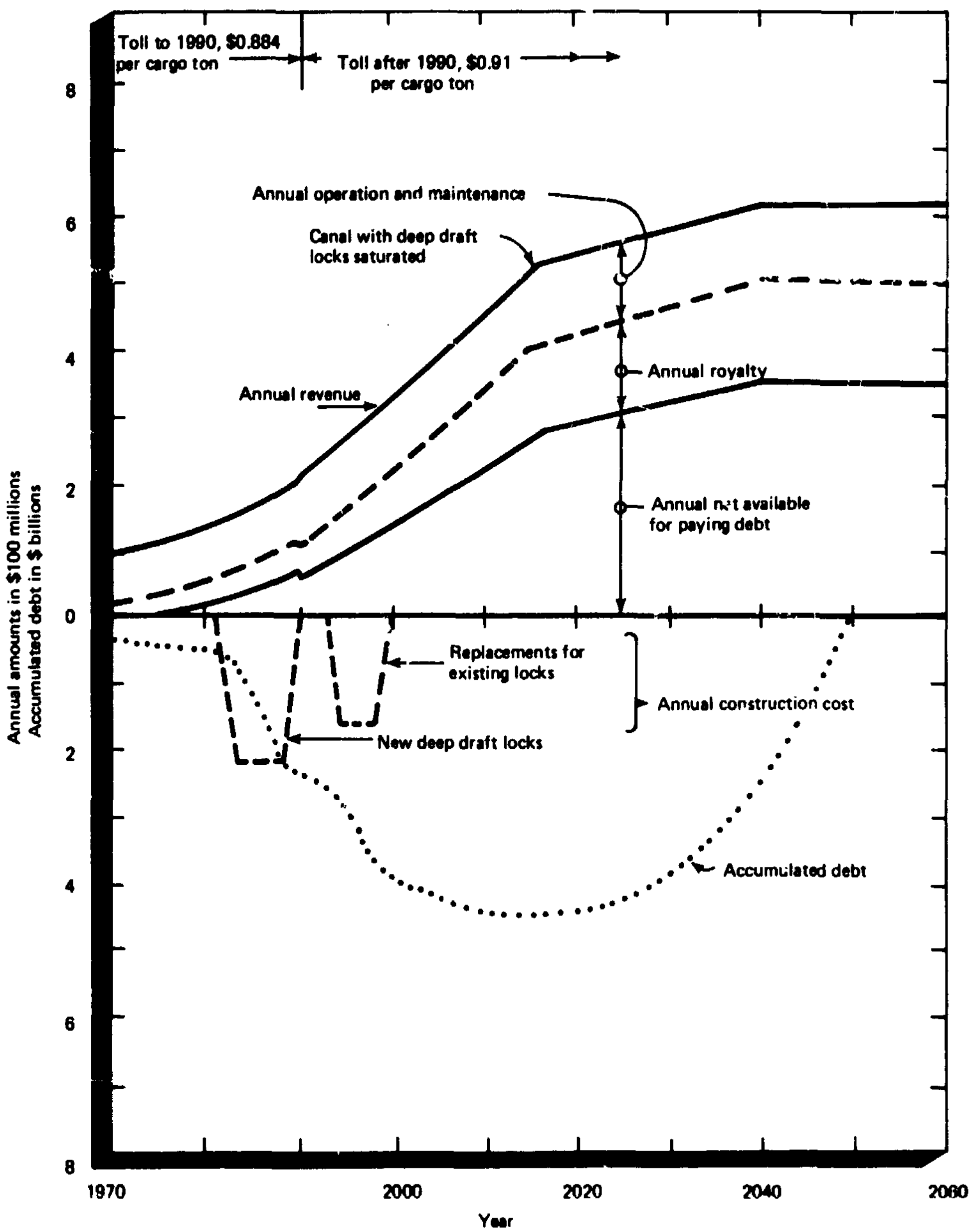
[2] Estimated in the Shipping Study using present Panama Canal toll structure and level. The decline in yield per cargo ton with the "potential" tonnage projection is a result of the decline in the percentage of cargo assumed to be carried in freighter from 46% in 1970 to 25% in 2000.



NOTES.
1. Construction cost for deep draft locks is $1.53 billion.
2. Existing locks not replaced.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. Deep draft locks open in 1990 for payout in 2050.
5. Potential tonnage and 25% mix used.
6. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
7. Interest is 6%.

ROUTE 15 CASH FLOW ANALYSIS

FIGURE A1-26



NOTES:
1. Construction cost of deep draft locks is $1.53 billion.
2. Construction cost of replacements for existing locks is $800 million.
3. Royalty reaches $0.22 per cargo ton in 1976.
4. Deep draft locks open in 1990 for payout in 2050.
5. Replacement locks open in 2000.
6. Potential tonnage and 25% mix used.
7. Canal financing assumed an extension of that of Panama Canal with a 1970 debt of $317 million.
8. Interest is 6%.

ROUTE 15 CASH FLOW ANALYSIS

FIGURE A1-27

date. Figure A1-28 shows how this date would vary with different interest rates. After the debt is paid off, a toll somewhat less than $0.60 per cargo ton (depending on the tonnage projection) would cover cost of operation and maintenance.

One financial advantage of the Panama Canal is apparent at this point. The Panama Canal, even with its more expensive operating organization, and paying interest at a greater rate then at present, would be debt-free sometime before 2000 while the sea-level canal options would not be free until 2060 if built under the most favorable circumstances including higher tolls.

Figure A1-29 develops this advantage further in that it shows the excess of revenues over costs by 2050, assuming various interest rates and "low" and "potential" tonnages. Also shown are the present values of these excesses. The values on this figure are comparable to zero accumulation and zero present value of Routes 10 and 14S if completed in 1990 and if substantially greater tolls were charged.

Ranking of Canal Options

One way of ranking the major canal options considered within the context of the "payout analysis" is by the toll per cargo ton which would have to be charged to liquidate the costs charged against each option after 60 years of operation. This ranking is given in Table A1-13 which assumes a 6% interest rate, start of operation of each new construction

TABLE A1-13

Canal Options Ranked by Self-Liquidating Tolls

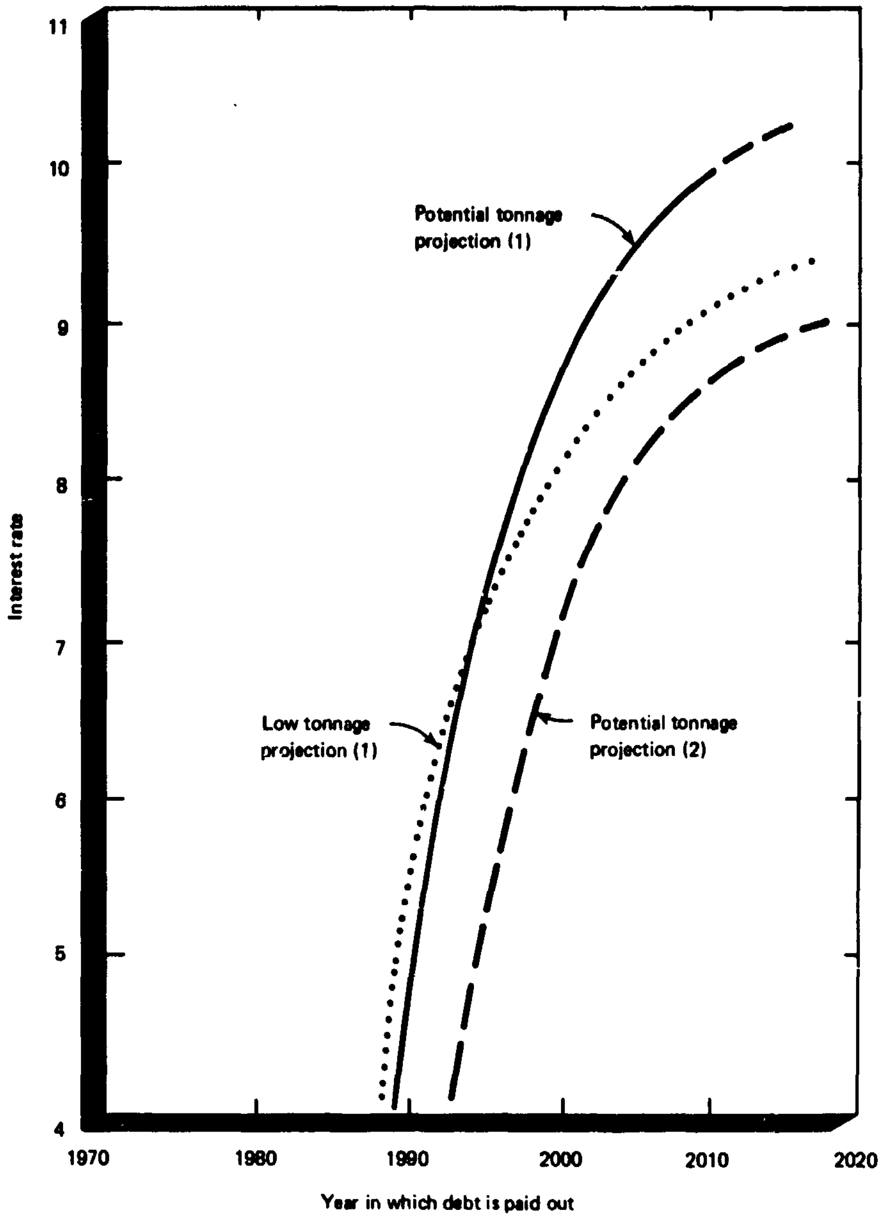
	Required Tolls per Cargo Ton[1]	
Canal Option	**"Low" Tonnage Projection**	**"Potential" Projection**
Present canal improved as recommended by Kearney	$0.59[2,3]	$0.49[2,3]
Present canal improved as recommended by Kearney and existing locks replaced in 2000	0.85[2,3]	0.78[2,3]
Route 15	0.89[3,4]	0.70[3,4]
Route 10	1.03	0.78
Route 14S	1.09	0.82
Route 15 with existing locks replaced in 2000	1.12[3,4]	0.92[3,4]

[1] Royalties reach $0.22 per cargo ton in 1976, tolls change from $0.884 per cargo ton at the start of construction of the canal option, canal option in service in 2000, financing of the canal option assumed an extension of that of Panama Canal, and all debts liquidated with interest at 6% after 60 years of operation.

[2] Required tolls after liquidating the cost of Kearney improvements and current debt on which Panama Canal Company pays interest and including cost of Canal Zone Government.

[3] Tug charges of $0.02 per cargo ton added to values derived from analyses to make them comparable to those for sea-level canal options.

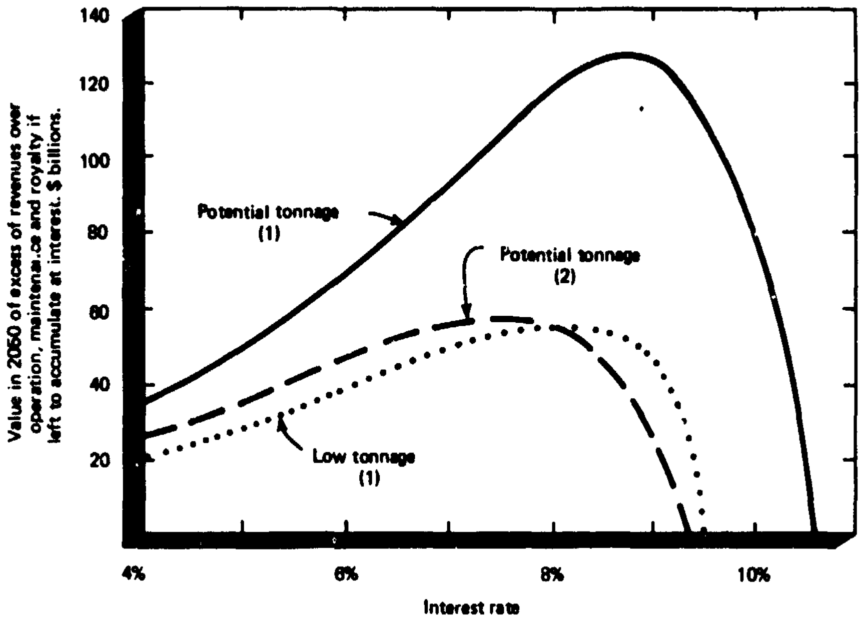
[4] Cost of Canal Zone Government included.

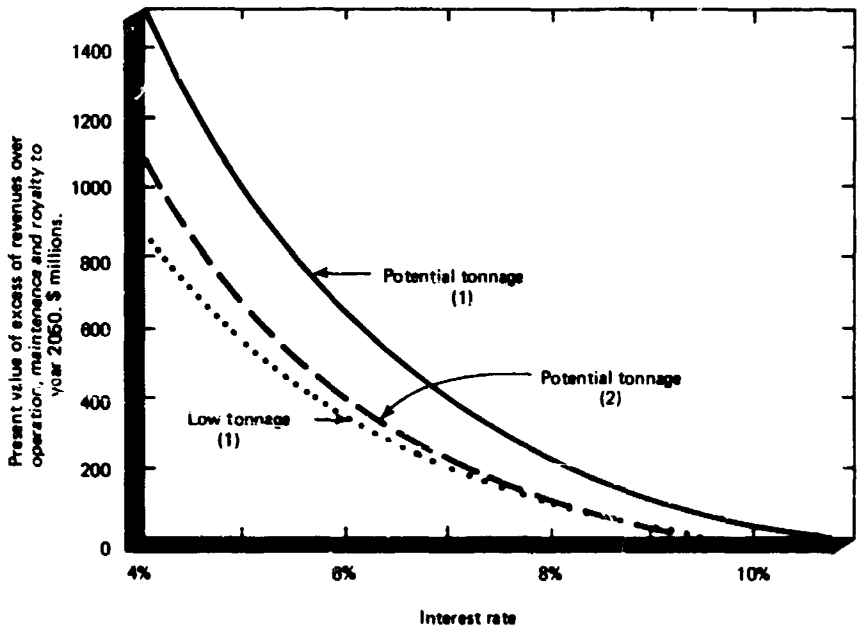


NOTES:
1. Toll rate assumed as $0.884 per cargo ton.
2. Tolls based on existing Panama Canal structure and rates.
3. 1970 Panama Canal debt assumed as $317 million.
4. $92 million canal improvement program assumed.
5. Royalties reach $0.22 in 1976.

PANAMA CANAL ESTIMATED PAYOUT DATE OF DEBT VS. INTEREST RATE

FIGURE A1-28





NOTES:

1. Tolls assumed as $0.884 per cargo ton.
2. Tolls based on existing Panama Canal System.
3. 1970 PCC debt of $317 million and $92 million improvement costs assumed paid out first.
4. Royalties reach $0.22 per cargo ton in 1976.
5. Neither deep draft locks nor replacement locks assumed to be constructed.

CONTINUED OPERATION OF PRESENT PANAMA CANAL

FIGURE A1-29

option in 2000, and a change of tolls from the assumed $0.884 per cargo ton to the required level at the start of construction of the option. The required tolls are given for both the "low" and the "potential" tonnage projections.

Summary

The results of the work described in this Appendix are summarized as follows:

1. The least expensive way to provide for transisthmian traffic consists of continuing the operation of the Panama Canal even though the canal will not meet the needs of ship size or annual transit capacity in the future.

2. The Panama Canal would provide the least expensive, though limited, service even if it were found necessary to replace the existing locks by the year 2000.

3. Route 15 would provide the next least expensive service, provided the existing locks need not be replaced. If the present locks require replacement by 2000, the sea-level canal options would provide less costly service.

4. Route 10 would provide less costly service than Route 14S, but more costly than the previously mentioned lock canal options except Route 15 if the present Panama Canal locks must be replaced in 2000.

5. Self-liquidating financing of Route 10 based on the "low" tonnage projection appears possible. One possible set of circumstances consists of the following:

   (1) Route 10 financing an extension of that of Panama Canal.

   (2) Start construction and change toll rate in about 1985 to the following on the basis of the "low" tonnage projection.

Interest Rate	Toll per Cargo Ton
6%	$1.02
7%	1.13
8%	1.27

   (3) If tonnages grow faster than the "low" rate, added capacity, if required, can be provided by constructing a bypass which could be paid for from revenues without increasing tolls.

6. If Route 10 were placed in operation in 2000 and the present Panama Canal toll structure were retained, the revenues would pay off the amounts indicated below, leaving unrecovered construction costs as also indicated below.

	Construction Cost in Billions	
Interest Rate	Recoverable	Unrecoverable
"Potential" tonnage projection		
6%	$2.9	$0.0
7%	2.1	0.8
7.6%	1.6	1.3
"Low" tonnage projection		
6%	2.0	0.9
6.7%	1.6	1.3

Source: Table A1-8.

THE ATLANTIC-PACIFIC INTEROCEANIC CANAL STUDY COMMISSION

Annex IV

Study of Interoceanic and Intercoastal Shipping

ANNEX IV

REPORT OF THE STUDY GROUP

ON

INTEROCEANIC AND INTERCOASTAL SHIPPING

Submitted to

The Atlantic-Pacific Interoceanic Canal Study Commission

April 1970

REPORT OF THE STUDY GROUP
ON
INTEROCEANIC AND INTERCOASTAL SHIPPING

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Chapter I

INTRODUCTION

Purpose of the Study

At the request of the Atlantic-Pacific Interoceanic Canal Study Commission, shortly after its appointment in mid-1965, the Secretary of Commerce agreed to provide the Chairman for an inter-departmental study group to determine the potential value of a new, sea-level Isthmian canal to United States and world shipping. The Office of the Under Secretary for Transportation was assigned the responsibility for this task, and the study chairmanship was transferred with this office to the newly created Department of Transportation in January 1967. In April 1969, the chairmanship reverted to the Department of Commerce, with the Maritime Administration assuming this responsibility.

The purpose of the Shipping Study was described by the Commission as follows:

> To analyze for the Commission the long-range (through year 2040) trends in intercoastal and interoceanic shipping related to the canal; to examine the interrelationships between a sea-level canal and shipping and finance; and in cooperation with other agencies and the Commission, to analyze the effects of selected toll collection and distribution plans upon interoceanic and intercoastal shipping.

Scope of the Study

The Commission's original instructions to the Shipping Study Group were in the form of a series of six questions:

1. What is the total demand for interoceanic freight transportation through year 2040, in terms of ships, cargoes, origins and destinations?
2. What changes will occur through year 2040 in the design and performance of ships and related transportation equipment which would bear upon future capacity requirements for the canal?
3. What will be the dimensions and operating characteristics of the largest commercial ships through year 2040, with or without a sea-level canal?
4. To what extent will the existing canal be adequate to meet shipping needs through year 2040?
5. What will be the effects of the sea-level canal upon intercoastal and interoceanic shipping?
6. Considering U.S. interests and the needs of world shipping, what policy for tolls collection and distribution should accompany the financing arrangement?

As study effort progressed to completion, the objectives of the study were refined to determine the following:

1. The ability of the Panama Canal to meet the future needs of world shipping, based in part on an analysis of historical traffic experience, current forces and trends in canal traffic, and canal capacity, to accommodate the numbers and sizes of ships for transit.

2. The nature and results of previous Panama Canal traffic studies in the light of actual experience to date, in order to facilitate adoption of the most practicable methodology for making a long-range forecast for future interoceanic canal traffic.

3. Potential cargo tonnage movements through an interoceanic canal based on examination of these considerations:

a. The latest trends in world and United States economic development and oceanborne trade.

b. Past and current trends in Isthmian canal cargo tonnage movements.

c. Historical and projected economic development of actual and potential regional users of an Isthmian canal.

d. Future plans of the shipping industry and major users of bulk carriers as they relate to potential canal traffic.

e. Technological developments in commercial transportation.

4. Potential transit projections through an interoceanic canal based on examination of these considerations:

a. Plans for world and United States port and harbor development.

b. Projected ship sizes and distribution for the world merchant fleet.

c. Projected ship sizes and distribution for potential canal traffic.

5. Potential revenues for use of a sea-level canal, to include consideration of tolls rates and relationship to potential traffic.

6. The preferred sea-level canal route alternative from the standpoint of interoceanic shipping interests.

Conduct of the Study

Under the successive chairmanship of the Assistant Secretary of Transportation for Policy Development and the Administrator, Maritime Administration, the Study Group was organized to include representation from the Department of Transportation, Department of Commerce (Maritime Administration), Department of State, Panama Canal Company, Department of Commerce (Business and Defense Services Administration), and Department of the Army. During the earlier phases of the study considerable attention was devoted to analyzing the Canal Study Commission's request for a forecast of potential Isthmian canal traffic and revenues extending some seventy years into the future. This request stemmed from two requirements. One was to predict the date at which the capacity of the existing lock canal with anticipated capital improvements would be inadequate to accommodate total demand for transit, and the other was to predict long-term capacity requirements and revenues for the purposes of designing a sea-level canal and evaluating its financial feasibility. At the outset, the Shipping Study Group advised the Commission that forecasts of future economic activities decrease in reliability very rapidly as their time span increases, and any forecast of canal shipping through the year 2040 must be highly tenuous. No such long-range forecast had been attempted in detail in earlier canal studies.

The initial approach of the Study Group was to obtain information on and make projections of population, gross national product, transportation technology, and ship sizes. An evaluation was made of the relationship between estimated economic growth in value terms and growth in ocean trade. Subsequent projections were developed for potential cargo tonnage volumes, transits and tolls volumes. Because of the difficulty of forecasting individual commodity movements over the extensive forecast period, projections of potential cargo tonnage movements were made only on an aggregate basis. The basic result was a specific forecast of potential cargo predicated on a continuation of uniform exponential growth.

Review of the preliminary study findings brought forth a wide range of views concerning forecasts of future Isthmian canal traffic in terms of potential cargo tonnage. It was apparent that large variations in the tonnage forecast would result from the various assumptions tendered. Consequently, it was decided to conduct a detailed reexamination of the economic factors that contribute to canal traffic and determine the range of possibilities. Emphasis was given to the principal causative factors in the growth of Panama Canal traffic since World War II, regional economic development as it relates to potential canal traffic, and petroleum movements.

The range which was considered is bounded by the high projection and the low tonnage forecast. The high projection assumes continuing growth at the average annual rate experienced by the Panama Canal over the past twenty years. The low tonnage forecast assumes a leveling off of traffic associated with the Japan trade; a slow incremental increase in all other trade; and an allowance for unforseeable trends. Within this wide range, a more detailed analysis relating canal traffic to world regional aggregations of gross national product was developed and forms the basis for the potential tonnage forecast, which is considered the basic forecast of this study for canal capacity and revenue planning purposes. The low tonnage forecast is considered valid for alternative revenue planning to demonstrate the degree of possible financial risk.

The next step in the study was to make a projection of the distribution of cargo by type ship that might use a canal of various sizes in accordance with the range of possibilities associated with an overall cargo tonnage forecast. Here, again, it was decided to use a range of possibilities concerning the cargo distribution of the future among freighters, dry bulk carriers and tankers, based on an analysis of Panama Canal cargo trends and projections of future world merchant fleet composition by type of vessel. A methodology, which included consideration of a ship efficiency index (the ratio of cargo tonnage transported in long to deadweight tons (DWT)) for each type ship and the average DWT per type of ship, was developed to convert the projected cargo mix into a projection of total transits for canal capacity and revenue planning purposes. Revenue computations were derived by using an average toll per ton of cargo for each type ship determined from current Panama Canal experience. In the projection of future shipping through an interoceanic Isthmian canal, consideration was given to plans for world and United States port and harbor development. Conclusions were reached concerning the capability of the Panama Canal with maximum improvements in canal facilities, operating procedures and water supply for lockages to meet the demand for future transits.

A revenue forecast was developed which comprises a range of estimates based on consideration of the following: the potential cargo tonnage forecast and the low tonnage

forecast; two ship cargo mixes; and two tolls systems. The tolls systems consist of the existing Panama Canal tolls rates and procedure of assessing charges and a system involving the use of maximum rates based on application of a marginal pricing concept. Conclusions were reached concerning the revenue potential of a sea-level canal, tolls rates, and structure.

The final step in the study was to make a comparative analysis of sea-level canal route alternatives from the standpoint of shipping interests. This analysis focused attention on the principal trade routes that contribute to Isthmian canal traffic.

Basic Assumption

For purposes of forecasting future demand for interoceanic canal utilization this study assumes that there will be no significant interruptions in world trade growth due to general war (major, worldwide) or economic depression (similar to 1930's).

Study Presentation

Chapter II examines existing Panama Canal capacity, tolls, and traffic trends. Chapter III presents a review of previous Panama Canal Traffic Studies. Chapter IV examines the economic factors that contribute to Isthmian canal traffic and provides estimates of the potential demand for interoceanic canal shipping services, to include forecasts of cargo tonnage movement, estimates of potential ship size and mix, and forecasts of transits for various Isthmian canal options. Chapter V estimates the revenue potential of a sea-level canal and evaluates the tolls system required to obtain various levels of revenue. Chapter VI presents conclusions derived from an analysis of data presented.

Chapter II

THE PRESENT CANAL

Introduction

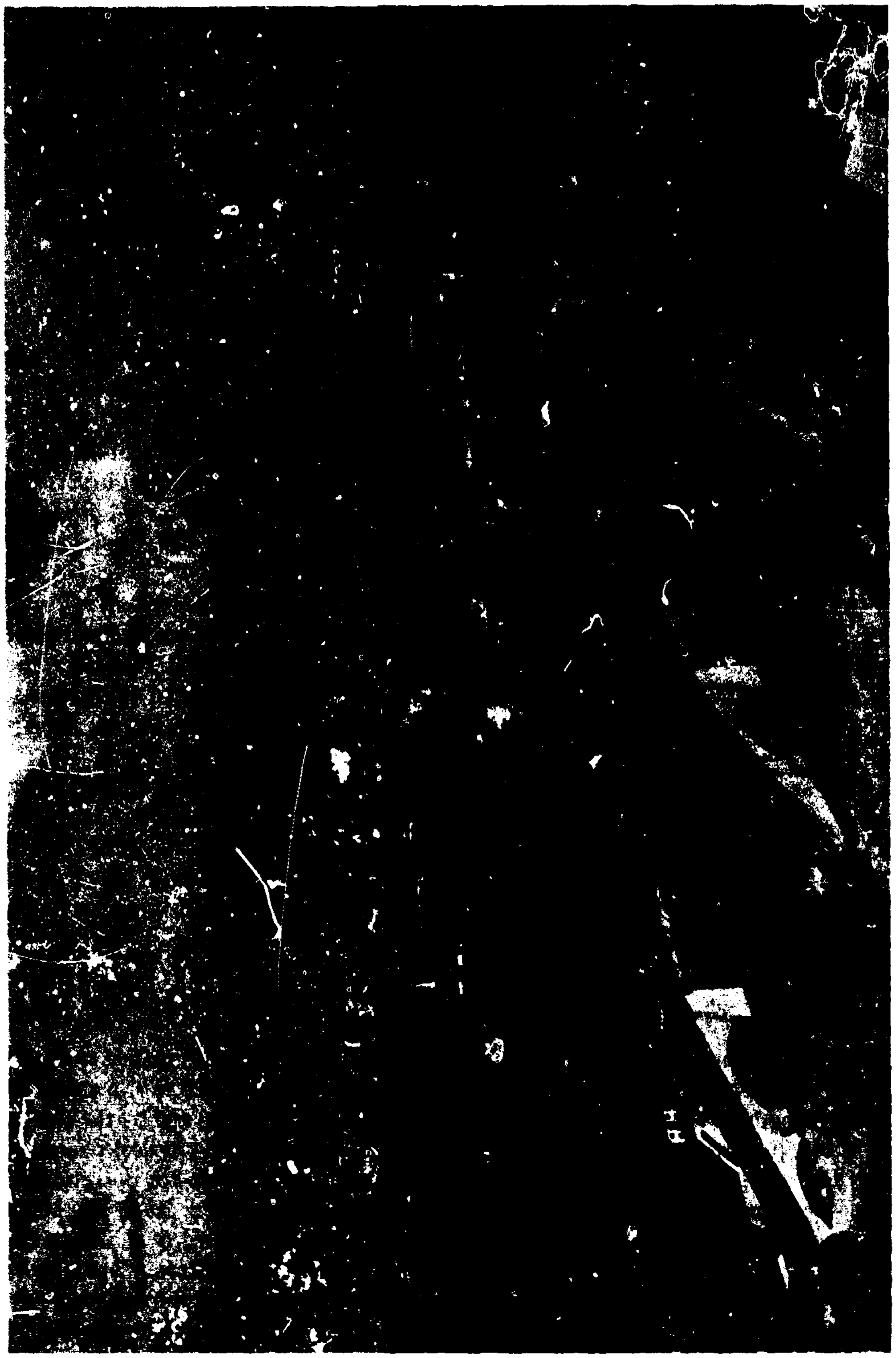
The Panama Canal is approximately 50 miles long, deep water to deep water, and follows a northwesterly to southeasterly direction. A ship entering the canal from the Atlantic goes from Cristobal Harbor to Gatun Locks, a distance of 7 miles, at sea level. It is lifted 85 feet to Gatun Lake in 3 lockages or "steps". From Gatun it sails, 85 feet above sea level, to Pedro Miguel, a distance of 31 miles. A single lockage at Pedro Miguel lowers the ship 31 feet to Miraflores Lake. A mile further south the vessel enters Miraflores Locks and, in 2 lockages, is lowered 54 feet to the Pacific Ocean level. A ship then sails 4 miles to the Balboa port area before entering the outer harbor.

The average time for a commercial ocean traffic vessel in Canal Zone waters in Fiscal Year 1969 was 16 hours. The average transit for the Canal proper takes 8 hours. The fastest transit was 4 hours and 38 minutes by the destroyer U.S.S. Manley. In Fiscal Year 1968, the transit of 15,511 vessels of all types established a new daily average record of 42.5 transits. In Fiscal Year 1969, the total number of transits declined slightly to 15,327 for a daily average of 42.0 transits.

The longest passenger vessel to transit the canal was the German flag BREMEN on February 15, 1939. She was a 51,731 gross-ton vessel with an overall length of 936.8 feet. The widest beamed commercial ships to transit are the oil-ore carriers SAN JUAN PIONEER and SAN JUAN PROSPECTOR, both 106.4 feet. Record cargo carried through the canal up to March 10, 1970, was aboard the bulk carrier ARCTIC which had a load of coal weighing 60,391 long tons. The ARCTIC has a length of 848.8 feet, a beam of 105.85 feet, and passed through the canal with a maximum draft of 39 feet 6 inches TFW.

Capacity

The capacity of the Panama Canal system is a matter of continuing, detailed study by the Panama Canal Company. It is measured by the capability of the canal to allow passage throughout its length on a sustained basis for a maximum number of ships and by the size of the locks which prescribes the largest size ship which can transit. The physical operating capacity of the canal is further constrained by the water supply available for operation of the locks. The Panama Canal Company completed in the summer of 1969 its latest comprehensive study of canal capacity. This study, which was conducted over a two-year period, is essentially an updating of previous studies to ensure that all factors which limit capacity are properly recognized and that all feasible means of augmenting capacity are considered. The Company's objective is to make the best possible determination of



Gatun Locks at the present Panama Canal

attainable capacity, and set up a program of improvements in methods, equipment and facilities which will best achieve this end.

Physical Characteristics

A major limitation on the capacity of the Panama Canal is the size of the lock chambers which are 110 feet wide and 1000 feet long. Completion of the widening of Gaillard Cut from 300 feet to 500 feet (scheduled for July, 1970) will eliminate another major limitation, except that the largest ships will not be able to pass one another in the Gaillard Cut. In order to overcome the effect of these physical restrictions, the Panama Canal Company has constantly developed procedures governing the operation of large ships.

The Company periodically publishes revised regulations pertaining to the size and draft limitations of vessels that may transit the canal. Restrictions with respect to beam and draft vary on a seasonal basis in accordance with Gatun Lake levels. Based on experience to date, the Company has determined that 106 feet is the widest beam commercial vessel acceptable for regular transit. Transit draft restrictions vary in accordance with beam, lake level, ship handling characteristics and other considerations. For practical purposes it appears that vessels in the transit draft range 40 feet and greater would be precluded from transit. Vessels in the transit draft range 36 to 40 feet are subject to draft restrictions. Depending on variable conditions, vessels in this range could either transit fully laden, transit partially laden or in ballast, or elect not to transit. The longest vessel that could be permitted transit would be approximately 950 feet in length. Panama Canal Company rules allow a 6-knot maximum speed for large ships in the Gaillard Cut section of the canal.

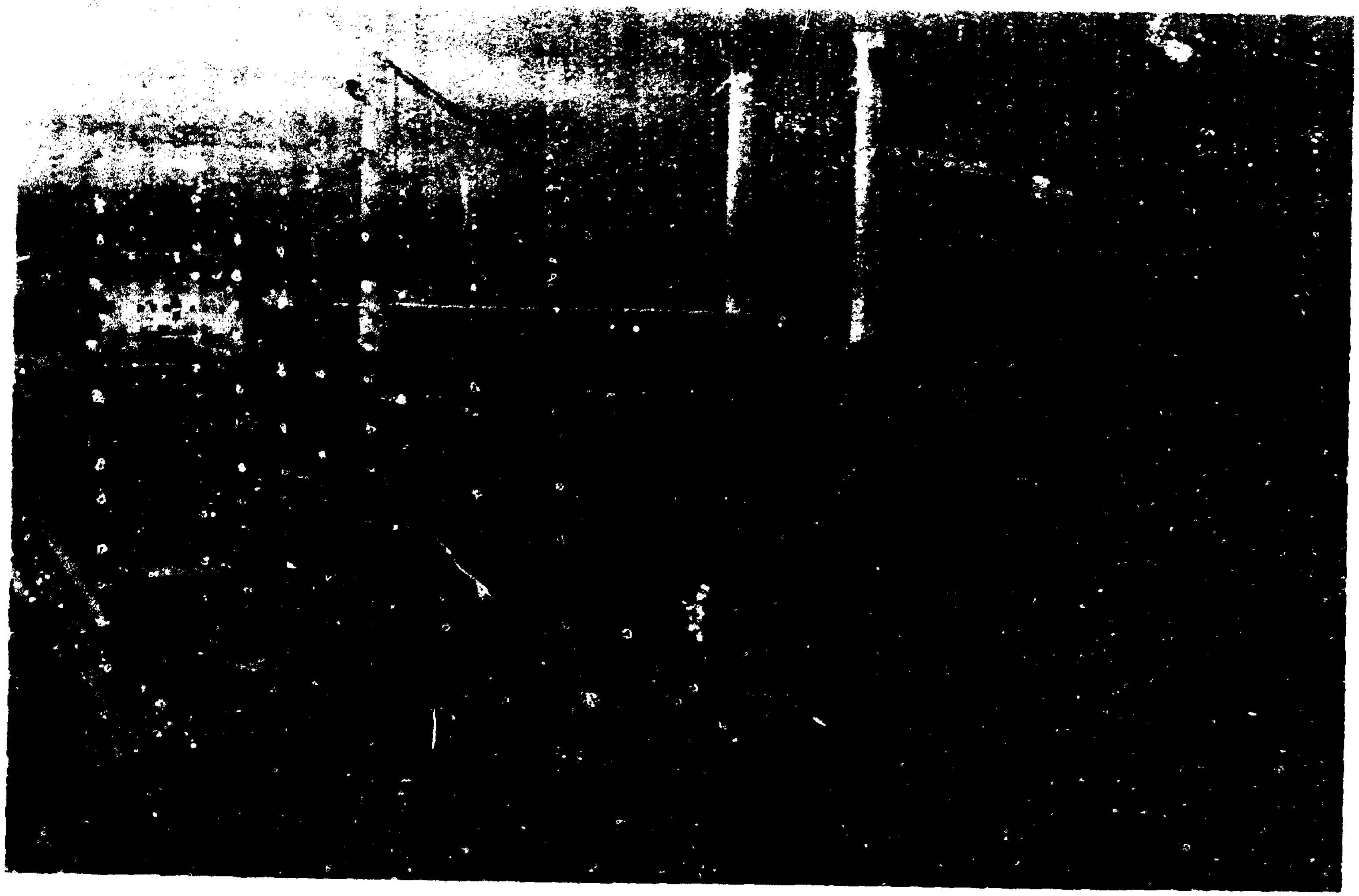
Number of Ships

The number of transits which can be handled annually depends upon physical operating capacity and future improvements in canal facilities and operating procedures. The recently completed Panama Canal Company study of canal capacity concludes that the ultimate physical operating capacity of the canal, with modernization and augmentation of water supply for lockages at an estimated cost of $92 million, is 26,800 annual transits.

Size of Ships

The Panama Canal is limited by draft and lock size to transit ships up to approximately 65,000 DWT when fully laden. As mentioned in the earlier discussion of physical characteristics of the canal, for all practical purposes ships in the world's merchant fleet that would be precluded from transiting the canal because of size are those that exceed 106 feet in beam and 950 feet in length. Vessels in the transit draft range 36 to 40 feet are subject to draft restrictions.

As of December 31, 1968, the world merchant fleet consisted of 19,361 vessels of 1,000 gross tons or over. As of January 1, 1970, there were 751 ships, primarily tankers, in the fleet too wide to enter the Panama Canal locks; as of November 27, 1969, there were 117 ships under construction and 446 on order too wide to transit the canal. In addition, the Panama Canal Company has determined that, as of January 1, 1970, there were between 604 and 1349 ships afloat (depending on variable Gatun Lake levels) unable to go through the locks fully laden because of draft restrictions. As of the same date, there were 87 under construction and 297 on order unable to go through the locks fully laden.



The S. S. ARCTIC with 60,391 long tons of coal passing through Miraflores Locks, March, 1970

Tolls

Basis of Toll Charges

Tolls are levied on a net capacity tonnage basis, Panama Canal measurement tons (a volume measurement). They amount to 90 cents a ton for laden ships and 72 cents unladen. These rates have remained essentially unchanged since the canal opened. A ship which would otherwise have to sail around Cape Horn can easily save many times the amount of her toll by using the canal. In Fiscal Year 1969, the average toll per oceangoing commercial transit was $6,651. The fact that Panama Canal tolls have not been adjusted as the U.S. dollar purchasing power decreased means that "real dollar" toll rates have been reduced effectively by three-fourths over the 55-year canal history.

Panama Canal tolls are based on the cargo carrying capacity of ships expressed in Panama Canal net tons, a measure roughly equal to 100 cubic feet of cargo space. The specific tolls rates are as follows:

1. On merchant vessels, Military Transports, tankers, hospital ships, supply ships, and yachts when carrying passengers or cargo: 90 cents per net vessel-ton of 100 cubic feet of actual earning capacity; that is, the net tonnage determined in accordance with the "Rules for the Measurement of Vessels for the Panama Canal."
2. On such vessels in ballast, without passengers or cargo: 72 cents per net vessel-ton.
3. On other floating craft: 50 cents per ton of displacement.

Tolls on laden vessels are not levied on the baiss of the amount or type of cargo carried. Vessels pay the laden rate whether the vessel has one ton of cargo or a capacity load of cargo. Tolls are not charged for a small volume of "free traffic" that includes ships of the Colombian and Panamanian Governments and ships transiting for repairs at the Panama Canal Company operated yards.

Table II-1 includes information on the average toll and credit per long ton of total cargo and the average toll per long ton of commercial ocean cargo for the period Fiscal Year 1915 through Fiscal Year 1969. The average toll/credit per long ton of total cargo is obtained by dividing the total annual tolls and credits revenue in a given year by the total number of tons of cargo that passed through the canal in that year. The average toll per long ton of commercial ocean cargo is computed in a similar manner. This average is not paid in fact by any ship. The basis of tolls charges is as described in the foregoing discussion.

Table II-1 shows that the average toll per long ton of cargo transited has remained relatively stable since the canal opened. Tolls credits were not charged for U.S. Government traffic prior to Fiscal Year 1952. For a more valid comparison of revenues through the span of years of operation since 1915 the approximate value of tolls credits for U.S. Government traffic prior to Fiscal Year 1952 has been provided by the Panama Canal Company. The figures for the average toll credit per total long ton of cargo prior to Fiscal Year 1952 represent an adjusted figure to reflect assumed charges for U.S. Government traffic.

Before World War II, the adjusted average toll per long ton of total cargo was somewhat above 90 cents. Subsequent to 1946, the low was about 78 cents in 1957 and the high was about 91 cents in 1953. There is no consistent trend in the average Panama Canal toll per long ton of cargo transited; however, the average for total traffic has not been below about 85 cents since 1957. Table II-1 shows that the average toll rate per long ton of commercial ocean traffic for most years during the period from 1947 to 1969 is between 80 to 90 cents per long ton.

TABLE II-1

PANAMA CANAL TRAFFIC, FISCAL YEARS 1915 THROUGH 1969

Fiscal Year	Total Transits	Commercial Ocean Transits	Total Traffic Long Tons of Cargo	Commercial Ocean Long Tons of Cargo	Total Tolls and Credits	Tolls Commercial Ocean Traffic	Average Toll/ Credit per Total Long Ton of Cargo*	Av. Toll per Comm. Ocean Long Ton of Cargo
1915	1,108	1,058	4,937,340	4,888,400	$ 4,367,602	$ 4,366,747	$.901	$.893
1916	807	724	3,166,200	3,093,335	2,407,047	2,403,089		
1917	1,937	1,738	7,210,065	7,054,720	5,628,068	5,620,800		
1918	2,210	1,989	7,570,178	7,525,768	6,439,066	6,428,780		
1919	2,230	1,948	7,015,400	6,910,097	6,173,028	6,164,291		
1920	2,777	2,393	9,731,232	9,372,374	8,514,207	8,504,939	.960	.908
1921	3,371	2,791	12,025,808	11,595,971	11,276,483	11,268,681		
1922	3,050	2,655	11,085,194	10,882,607	11,198,000	11,191,829		
1923	4,449	3,908	19,780,163	19,566,429	17,508,701	17,504,027		
1924	5,787	5,158	27,219,471	26,993,167	24,291,596	24,284,660		
1925	5,174	4,592	24,170,360	23,956,549	21,400,994	21,393,718	.915	.893
1926	5,923	5,087	26,153,375	26,030,016	22,931,764	22,919,932		
1927	6,259	5,293	27,976,818	27,733,555	24,230,027	24,212,251		
1928	7,116	6,253	29,863,398	29,615,651	26,945,862	26,922,201		
1929	7,197	6,289	30,781,755	30,647,768	27,128,893	27,111,125		
1930	6,875	6,027	30,163,735	30,018,429	27,077,267	27,059,999	.935	.901
1931	6,217	5,370	25,214,573	25,065,283	24,646,109	24,624,600		
1932	5,075	4,362	19,929,450	19,798,986	20,707,856	20,694,705		
1933	5,040	4,162	18,269,917	18,161,165	19,621,181	19,601,077		
1934	6,211	5,234	24,889,799	24,704,009	24,065,707	24,047,183		
1935	6,369	5,180	25,400,052	25,309,527	23,339,239	23,307,063	.919	.921
1936	6,453	5,382	26,632,360	26,505,943	23,510,629	23,479,114		
1937	6,695	5,387	28,225,212	28,108,375	23,147,640	23,102,137		
1938	6,930	5,524	27,552,904	27,385,924	23,215,208	23,169,889		
1939	7,479	5,903	27,993,144	27,866,627	23,699,430	23,661,021		
1940	6,945	5,370	27,523,907	27,299,016	21,177,759	21,144,675	.800	.775
1941	6,623	4,727	25,198,600	24,950,791	18,190,380	18,157,740		

(Continued on following page)

TABLE II-1

PANAMA CANAL TRAFFIC, FISCAL YEARS 1915 THROUGH 1969 (Cont'd.)

Fiscal Year	Total Transits	Commercial Ocean Transits	Total Traffic Long Tons of Cargo	Commercial Ocean Long Tons of Cargo	Total Tolls and Credits	Tolls Commercial Ocean Traffic	Average Toll/ Credit per Total Long Ton of Cargo*	Av. Toll per Comm. Ocean Long Ton of Cargo
1942	4,643	2,688	14,187,080	13,607,444	$ 9,772,113	$ 9,752,207		
1943	4,372	1,822	11,030,105	10,599,966	7,368,739	7,356,685		
1944	5,130	1,562	11,592,677	7,003,487	5,473,846	5,456,163		
1945	8,866	1,939	19,369,141	8,603,607	7,266,211	7,243,602	$1.06	$.842
1946	9,586	3,747	22,469,152	14,977,940	14,796,406	14,773,693	1.34	.986
1947	6,375	4,260	22,688,425	21,670,518	17,634,361	17,596,602	.878	.811
1948	6,999	4,678	25,664,205	24,117,788	20,017,439	19,956,593	.850	.827
1949	7,361	4,793	27,782,588	25,305,158	20,617,635	20,541,230	.831	.812
1950	7,694	5,448	30,364,982	28,872,293	24,511,713	24,430,206	.874	.846
1951	7,751	5,593	31,281,525	30,073,022	23,958,879	23,906,082	.855	.795
1952	9,169	6,524	36,902,908	33,610,509	30,409,500	26,922,532	.824	.801
1953	10,210	7,410	41,203,401	36,095,349	37,530,327	31,917,515	.911	.884
1954	10,218	7,784	41,882,368	39,095,067	37,191,107	33,247,864	.888	.850
1955	9,811	7,997	41,548,037	40,646,301	35,136,529	33,849,477	.846	.833
1956	9,744	8,209	46,331,901	45,119,042	37,450,759	36,153,842	.809	.801
1957	10,169	8,579	50,659,057	49,702,200	39,653,712	38,444,128	.783	.773
1958	10,608	9,187	48,982,036	48,124,809	42,834,005	41,795,905	.874	.868
1959	11,192	9,718	52,328,987	51,153,096	46,546,620	45,528,728	.890	.890
1960	12,147	10,795	60,401,733	59,258,219	51,803,032	50,939,428	.858	.860
1961	12,019	10,866	65,216,581	63,669,738	55,172,719	54,127,877	.846	.850
1962	12,106	11,149	69,063,475	67,524,552	58,347,290	57,289,705	.845	.848
1963	12,005	11,017	63,877,200	62,247,092	57,885,931	56,368,073	.906	.906
1964	12,945	11,808	72,168,690	70,550,090	62,546,390	61,098,312	.867	.866
1965	12,918	11,834	78,922,931	76,573,071	67,148,451	65,442,633	.851	.855
1966	13,304	11,925	85,323,463	81,703,514	72,594,110	69,095,129	.851	.846
1967	14,070	12,412	92,997,958	86,193,430	82,296,638	76,768,605	.885	.891
1968	15,511	13,199	105,538,318	96,550,165	93,153,649	83,907,062	.883	.869
1969	15,327	13,150	108,793,069	101,391,132	95,914,608	87,457,895	.882	.863

*Note: Tolls credits for U.S. Government Traffic commenced in FY 1952. Figures for preceding years show adjusted average toll/credit if U.S. Government Traffic had been included.

SOURCE: Panama Canal Company Annual Reports

Elements of Cost Recovered

The canal cost the United States approximately $387 million to build. When it opened in 1914, the United States did not contemplate its operation on a self-amortizing basis. Tolls were set at a reasonable level that would encourage the use of the canal by the world's merchant shipping. From 1914 to 1951 the canal was financed by annual appropriations from the U.S. Treasury while its annual receipts were returned to the Treasury. Not until after World War II did income approach operating costs. In 1951 the Panama Canal Company was organized as a U.S. Government corporation under legislation which authorized the Company to set tolls at rates sufficient to recover annual operating costs, interest on the unamortized U.S. original investment, depreciation, and the net cost of the Canal Zone Government. If, in any given year, the cash on hand exceeds the amount required for working capital and foreseeable plant replacement or expansion, the excess is required to be paid into the United States Treasury and applied to amortization of the capital investment. When the Panama Canal Company was organized in 1951, the unamortized U.S. investment which the Company established after audit by the General Accounting Office and with the approval of the Bureau of the Budget was $373 million as of July 1, 1951. The interest bearing investment, as of June 30, 1969, is approximately $317 million.

Tolls Revenues by Type of Ship

Table II-2 shows transits and tolls for commercial ocean traffic by ship classification for the period Fiscal Year 1946 through Fiscal Year 1969. General cargo ships include all cargo ships constructed or modified to special Panama Canal rules. General cargo ships include all cargo ships except the tankers and ore ships. Tankers are designed for liquid cargoes. However, Panama Canal Company statistics normally do not distinguish tankers carrying petroleum products from those carrying dry bulk grain.

The data for Fiscal Years 1968 and 1969 have been consolidated in Table II-2 for comparison with the data of the preceding years. However, in Fiscal Year 1968 the Panama Canal Company commenced subdividing what had been the General Cargo category into several others, i.e., combination carriers, container cargo ships, dry bulk carriers, general cargo ships, and refrigerated cargo ships. For study purposes these data have been rearranged into the groupings indicated in Table II-3.

By 1968-1969 the number of commercial ocean traffic transits had increased about 3.5 times over those in 1946, and the tolls collected had increased about 5.5 times over those in 1946, reflecting the increase in average size of ships transited.

Table II-4 indicates that general cargo ships (including dry bulk carriers, combination carriers, container cargo ships, and refrigerated cargo ships) have accounted for about 80 per cent of canal transits and 75 per cent of tolls in recent years. Tanker transits have averaged between 10 and 15 per cent; tanker tolls have ranged between 15 and 20 per cent. Ore and passenger ships have declined percentage-wise in the post-war period in transits and tolls paid. Further analysis of tolls revenue by type of ship is included in Chapter V, Potential Revenue for Use of a Sea-Level Canal.

Traffic

Table II-1 portrays basic data on transits, cargo tonnage, and tolls and credits for Panama Canal traffic from the opening of the canal through Fiscal Year 1969.

TABLE II-2

PANAMA CANAL TRANSITS AND TOLLS BY TYPE OF SHIP
COMMERCIAL OCEAN TRAFFIC, 1946-1969

Fiscal Year	Tankers[1] Transits	Tankers[1] Tolls	Ore Ships Transits	Ore Ships Tolls	Passenger Ships Transits	Passenger Ships Tolls	General Cargo[2] Transits	General Cargo[2] Tolls	Other Transits	Other Tolls	Naval Ships Transits	Naval Ships Tolls	Total Transits	Total Tolls	Average Toll per Commercial L.T.
	(no.)	($000)	(no.)	($000)	(no.)	($000)	(no.)	($000)	(no.)	($000)	(no.)	($000)	(no.)	($000)	($)
1946	449	$ 2,206	56	$ 135	91	$ 481	3,105	$11,801	4	$ 5	42	$ 80	3,747	$14,773	.986
1947	367	1,833	140	494	208	1,171	3,494	[illegible]	37	26	14	40	4,260	17,596	.811
1948	393	1,797	172	606	278	1,686	3,798	15,818	23	19	14	30	4,678	19,956	.827
1949	398	1,823	253	912	306	1,80[illegible]	3,784	15,893	30	53	22	56	4,793	20,541	.812
1950	655	3,698	216	776	337	1,984	4,215	17,957	16	9	9	6	5,448	24,430	.846
1951	444	2,326	235	846	294	1,748	4,579	18,941	20	18	21	27	5,593	23,906	.795
1952	612	3,135	189	684	316	1,920	5,372	21,106	11	23	24	54	6,524	26,922	.801
1953	931	4,991	161	578	347	2,120	5,943	24,180	10	5	18	38	7,410	31,917	.884
1954	833	4,406	153	562	320	2,014	6,433	26,181	19	26	26	65	7,784	33,247	.850
1955	838	4,724	124	543	312	1,976	6,654	26,476	25	57	44	68	7,997	33,849	.833
1956	878	5,391	181	1,015	326	2,123	6,753	27,530	19	31	52	63	8,209	36,153	.801
1957	725	4,499	260	1,311	333	2,225	7,202	30,299	20	33	39	77	8,579	38,444	.773
1958	890	5,792	348	1,764	331	2,232	7,563	31,934	30	31	25	39	9,187	41,795	.868
1959	1,068	7,354	371	1,857	315	2,175	7,898	34,055	30	31	36	56	9,718	45,528	.890
1960	1,064	7,873	489	2,921	286	2,063	8,883	37,982	23	14	50	96	10,795	50,939	.860
1961	1,116	8,905	345	2,332	295	2,148	9,047	40,650	20	22	43	70	10,866	54,127	.850
1962	1,137	8,981	261	2,126	302	2,233	9,335	43,787	64	95	40	67	11,149	57,289	.848
1963	1,345	9,678	260	2,169	395	2,248	8,950	42,065	127	159	40	49	11,017	56,368	.906
1964	1,334	9,901	211	2,215	337	2,892	9,706	45,821	178	221	42	48	11,808	61,098	.866
1965	1,642	12,671	165	2,056	325	2,807	[illegible]	47,644	93	163	54	101	11,834	65,442	.855
1966	1,699	13,653	154	2,016	266	2,393	[illegible]	50,756	104	182	60	99	11,925	69,095	.846
1967	1,923	15,896	85	1,258	273	2,572	[illegible]	56,787	102	172	41	84	12,412	76,768	.891
1968	2,030	14,847	17	215	308	2,889	10,626	65,442	[illegible]	411	51	103	13,199	83,907	.869
1969	2,081	15,568	21	213	298	2,862	10,548	[illegible]	152	325	50	89	13,150	87,458	.863

[1] Although tankers frequently lift grain cargoes, these figures do not distinguish tankers carrying petroleum products from those carrying dry bulk grain.

[2] Figures include all cargo ships except tankers and ore ships.

SOURCE: Annual Reports, Panama Canal Company

TABLE II-3

PANAMA CANAL TRANSITS AND TOLLS BY TYPE OF SHIP, COMMERCIAL OCEAN TRAFFIC, FY 1968 & 1969

Type of Vessel	Transits (Number)		Tolls ($000)	
	FY 1968	FY 1969	FY 1968	FY 1969
Tank Ships	2,030	2,081	$14,847	$15,568
Dry Bulk Carriers	1,915	2,255	$22,328	$27,472
(Dry Bulk Carriers)	(1,784)	(2,125)	(20,157)	(25,103)
(Combination Carriers)	(114)	(109)	(1,956)	(2,156)
(Ore Ships)	(17)	(21)	(215)	(213)
Freighters	9,036	8,612	$46,218	$44,004
(Container Cargo Ships)	(55)	(61)	(365)	(376)
(General Cargo Ships)	(6,847)	(6,348)	(37,584)	(34,588)
(Passenger Ships)	(308)	(298)	(2,889)	(2,862)
(Refrigerated Cargo Ships)	(1,826)	(1,905)	(5,380)	(6,178)
Other	167	152	$ 411	$ 325
Naval Ships	51	50	$ 103	$ 89
GRAND TOTAL	13,199	13,150	$83,907	$87,458

SOURCE: Panama Canal Company Annual Reports, FY 1968 and FY 1969

Panama Canal traffic is subdivided into several categories for purposes of statistical analysis. For an overview of the total cargo tonnage transiting the canal in any given year, as well as numbers of transits and tolls, the following categories comprise the sum of the total:

Commercial ocean traffic – Includes ships of 300 net tons and over, Panama Canal measurement, or of 500 displacement tons and over on vessels paying tolls on displacement basis (dredges, warships, etc.).

U.S. Government ocean traffic – Same criteria as commercial ocean traffic except that ships are owned by or operated under contract for the United States Government.

Free ocean traffic – Includes ships of the Colombian and Panamian Governments and ships transiting for repairs at Panama Canal Company operated yards.

TABLE II-4

PANAMA CANAL TRANSITS AND TOLLS BY TYPE OF SHIP, COMMERCIAL OCEAN TRAFFIC PERCENTAGE DISTRIBUTION, 1946-1969

Fiscal Year	Tankers		Ore Ships		Passenger Ships		General Cargo		Other		Naval Ships		Total	
	Transits	Tolls	Transits	Tolls	Transits	Tolls	Transits	Tolls	Transits	Tolls	Transits	Tolls	Transits	Tolls
1946	12.0%	14.9%	1.5%	1.3%	2.4%	3.3%	82.0%	79.9%	0.1%	a	1.1%	0.5%	100.0%	100.0%
1947	8.6	10.4	3.3	2.8	4.9	6.7	82.0	79.7	0.9	0.1%	0.3	0.2	100.0	100.0
1948	8.4	9.0	3.7	3.0	5.9	8.4	81.2	79.3	0.5	0.1	0.3	0.2	100.0	100.0
1949	8.3	8.9	5.3	4.4	6.4	8.8	78.9	77.4	0.6	0.2	0.5	0.3	100.0	100.0
1950	12.0	15.1	4.0	3.2	6.2	8.1	77.3	73.5	0.3	0.1	0.2	a	100.0	100.0
1951	7.9	9.7	4.2	3.5	5.3	7.3	81.9	79.2	0.4	0.1	0.4	0.1	100.0	100.0
1952	9.4	11.6	2.9	2.5	4.8	7.1	82.3	78.4	0.2	0.1	0.4	0.2	100.0	100.0
1953	12.6	15.6	2.2	1.8	4.7	6.6	80.2	75.8	0.1	0.1	0.2	0.1	100.0	100.0
1954	10.7	13.3	2.0	1.7	4.1	6.1	82.6	78.6	0.2	a	0.3	0.2	100.0	100.0
1955	10.5	14.0	1.6	1.6	3.9	5.8	83.2	78.2	0.3	0.2	0.6	0.2	100.0	100.0
1956	10.7	14.9	2.2	2.8	3.9	5.9	82.3	76.1	0.2	0.1	0.6	0.2	100.0	100.0
1957	8.5	11.7	3.0	3.4	3.9	5.8	83.9	78.8	0.2	0.1	0.5	0.2	100.0	100.0
1958	9.7	13.9	3.8	4.2	3.6	5.3	82.3	76.4	0.3	0.1	0.3	0.1	100.0	100.0
1959	11.0	16.2	3.8	4.0	3.2	4.8	81.3	74.8	0.3	0.1	0.4	0.1	100.0	100.0
1960	9.9	15.4	4.5	5.7	2.7	4.0	82.3	74.6	0.2	a	0.5	0.2	100.0	100.0
1961	10.2	16.5	3.2	4.3	2.7	4.0	83.3	75.0	0.2	a	0.4	0.1	100.0	100.0
1962	10.2	15.7	2.4	3.7	2.7	3.9	83.7	76.4	0.6	0.1	0.4	0.1	100.0	100.0
1963	12.0	17.2	2.4	3.8	2.7	4.0	81.2	74.6	1.2	0.3	0.4	0.1	100.0	100.0
1964	11.3	16.2	1.8	3.6	2.9	4.7	82.2	75.0	1.5	0.4	0.4	0.1	100.0	100.0
1965	13.9	19.4	1.4	3.1	2.7	4.3	80.7	72.8	0.8	0.2	0.5	0.2	100.0	100.0
1966	14.2	19.7	1.3	2.9	2.2	3.5	80.9	73.4	0.9	0.3	0.5	0.2	100.0	100.0
1967	15.5	20.7	0.7	1.6	2.2	3.4	80.5	74.0	0.8	0.2	0.3	0.1	100.0	100.0
1968	15.5	17.7	0.1	0.3	2.3	3.4	80.5	78.0	1.2	0.5	0.4	0.1	100.0	100.0
1969	15.8	17.8	0.1	0.2	2.3	3.3	80.2	78.2	1.2	0.4	0.4	0.1	100.0	100.0

a Negligible

SOURCE: Analysis of Panama Canal Company Annual Reports

Small commercial traffic – Includes vessels under 300 net tons, Panama Canal measurement (or under 500 displacement tons for vessels assessed on displacement tonnage).

Small U.S. Government traffic – Same measurement criteria as small commercial traffic.

Small free traffic – Same measurement criteria as small commercial traffic.

Table II-1 breaks out commercial ocean traffic which represents the greatest amount by far of cargo tonnage that transits the Panama Canal. All other categories are included in the total tonnage and tolls (except for free traffic) columns.

About 5 million long tons of cargo passed through the Panama Canal during the initial year of operation. Landslides prevented operations through much of 1916 and limited traffic to approximately 3 million long tons. Although cargo tonnage more than doubled in 1917 it remained relatively constant until the post-World War I recovery of the early 1920's after which steady growth occurred through 1929 to almost 31 million long tons. World-wide depression affected growth adversely in the 1930's and World War II reduced the total cargo tonnage transited to 11 million long tons in 1943. Post-World War II recovery has been relatively steady, reaching a record high of 108.8 million long tons of cargo in 1969.

The limited wars in which the United States has been involved since World War II have had an impact on Panama Canal traffic. The major impact of the Korean War is illustrated by the considerable increase in total cargo tonnage in the early 1950's and then a levelling off in the mid-1950's. This was due to the sharp rise in U.S. Government ocean traffic which reached a peak in Fiscal Year 1953 and then dropped off to normal experience in 1955 and 1956. This overall effect on growth was only temporary, however; commercial cargo tonnage continued to grow and made a great surge in 1956, causing a corresponding surge in total cargo tonnage.

Logistical support of military operations in Southeast Asia has had a significant bearing on the continued substantial growth of Panama Canal traffic in recent years. The Panama Canal Company attributes the war in Vietnam as being a major factor in the increase in all areas of canal traffic with the principal impact being on U.S. Government ocean traffic. Commercial traffic is also considered to have been affected indirectly through increased U.S. offshore expenditures which have given added economic impetus to other canal users, principally Japan. The post-war situation in Vietnam will probably have a temporary effect on growth of Panama Canal traffic comparable to that experienced after the Korean War.

Another development that has contributed to the recent surge in canal traffic is the closure of the Suez Canal, which according to the Panama Canal Company has affected both commercial and U.S. Government traffic. Principally affected have been vessels normally plying the route from various eastern Europena, Mediterranean, and Black Sea ports to the Far East which are now rerouting via the longer Panama Canal route. In addition, U.S. Government vessels which previously transited Suez to Vietnam have now been added to the Panama Canal traffic pattern.

Panama Canal trade is analyzed in detail in Chapter IV, Isthmian Canal Traffic Forecast Among the outstanding features of this trade have been the decline in United States intercoastal trade and the remarkable increase in cargo movements (primarily from the East Coast United States) to Japan, owing to continuous Japanese economic expansion from the mid-1950's to the present.

Chapter III

REVIEW OF PREVIOUS PANAMA CANAL TRAFFIC STUDIES

Introduction

Certain traffic projections predated the decision to construct the Panama Canal, but the weight of existing evidence suggests that the decision to build the canal resulted more from a general recognition of political, economic, and military advantage to the United States as a new world power than from any quantitative analysis. In designing the locks in the early part of the Twentieth Century, the Panama Canal engineers attempted to provide ample lock capacity for the largest ships that might ever be constructed. Several separate forecasts of future traffic through the Panama Canal were prepared from 1912 through World War II. Those that were made in the earlier part of this period could not foresee the significant drop in Panama Canal traffic which resulted from the economic dislocation in Europe in the 1920's and in the United States in the 1930's. Those that spanned the period 1939-1945 did not foresee – understandably so – the dramatic decrease in traffic during World War II.

Each traffic forecast was based on either **disaggregation** or **aggregation** as an economic theory underlying the method of projection. The disaggregative technique involves an approach which derives the sum-of-components by forecasting changes in each component. Disaggregation is most appropriately used in forecasting when component data are available, understandable, and changes in them predictable in logical and statistical terms. This is characteristically found in short-range forecasts which emphasize the expected changes of specific components. In terms of Panama Canal traffic forecasts, analysis has proven that forecasts of changes in existing components become of decreasing reliability as the period of forecast is extended. Perhaps the greatest disadvantage of this technique is the inability of the projector to foresee the development of new components.

The **aggregative** technique, in contrast to **disaggregation**, forecasts the total by examining the historical relationship of the total growth function and its components in a time series sequence. This relationship, either linear or otherwise, is employed in a forecast by projecting the total on the basis of its demonstrated pattern of growth to derive the growth of its components. The economic implication here is grounded in an observation that the overall growth of economic development has an influence of causation on components of economic activity. Economists are often uncertain as to whether this relationship is purely statistical in nature or more meaningful in a substantive way. Nevertheless, the technique affords a means by which to project long-term growth rates in aggregate growth functions in which there is no reliable basis for forecasting the growth rates of individual components and in which the entrance and growth of new components cannot be foreseen.

Panama Canal Post – World War II Traffic Forecasts

The following presents a survey of previous canal traffic forecasts conducted subsequent to World War II. These and a few earlier forecasts are shown in Figure III-1.

Isthmian Canal Studies – 1947

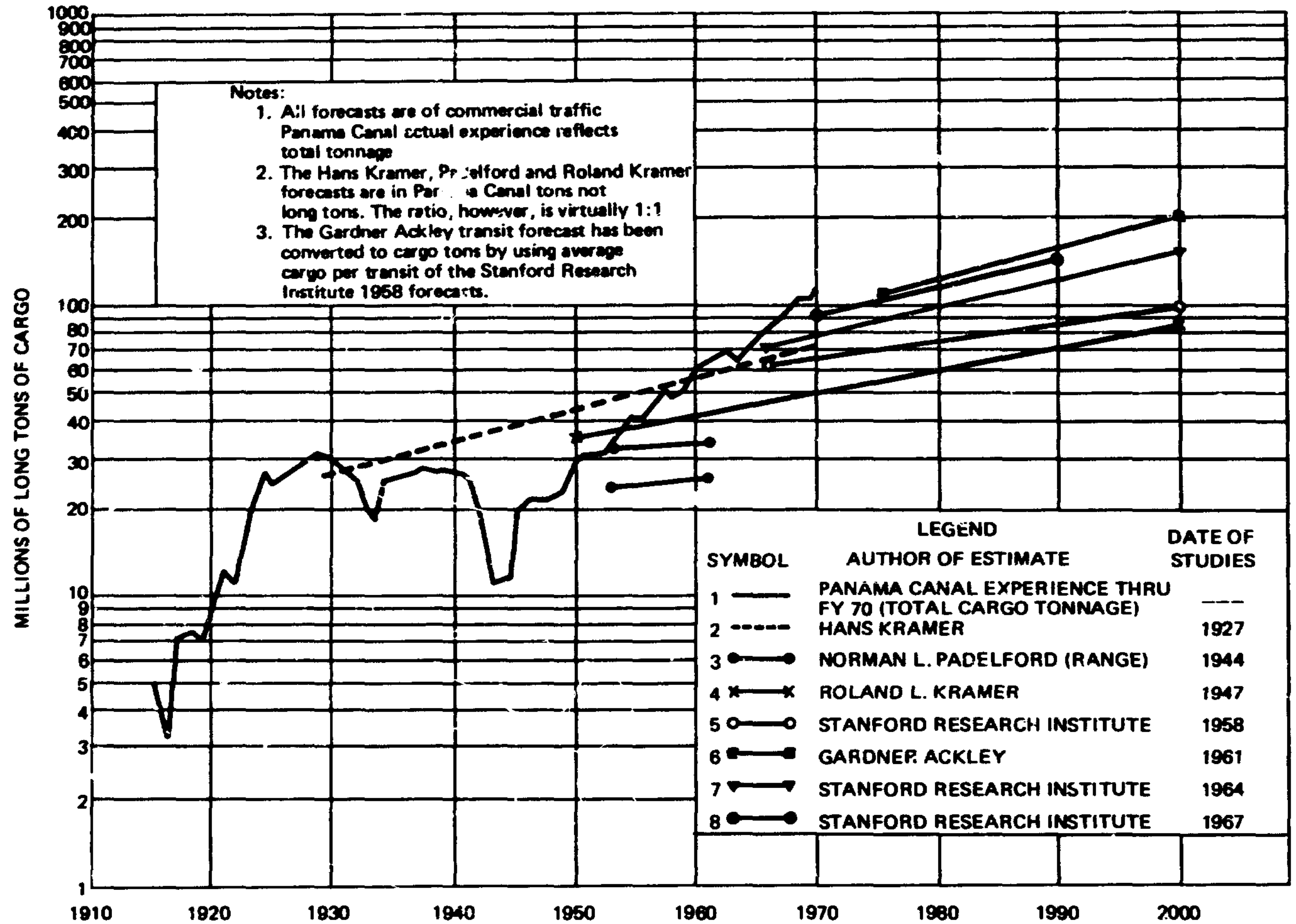
These studies comprised a comprehensive investigation by the Governor of the Panama Canal of the means of increasing the capacity and security of the Panama Canal. They included a traffic survey conducted under the direction of Dr. Roland L. Kramer of the Wharton School of Finance and Commerce. The purpose was to forecast the volume of commercial traffic through the Panama Canal annually for the period 1950-2000. The study resulted in four traffic projections. Two were based on ecomomic-statistical projections – one relating the several segments of Panama Canal traffic to corresponding national income estimates and the other drawn to reflect official estimates of United States export-import trade. A third projection, a historic trend line, was based upon Panama Canal experience during the period 1923-1936 and held petroleum traffic constant at the 1936 tonnage experience. A fourth projection was based upon an application of Panama Canal traffic to the longer historic pattern of Suez Canal traffic. The four projections were evaluated in the light of the following influences: commodity analyses; analysis of the future trade of countries and areas served by the Panama Canal; and shipping company plans for future use of the Panama Canal. The 1947 Panama Canal Commercial Traffic Survey utilized an aggregative approach in projection.

The Kramer Study accepted the economic-statistical projection based on national income estimates as a reasonable maximum forecast of commercial traffic, and trends based on Panama and Suez Canal experience as the minimum amount of traffic likely to materialize in the future. The economic-statistical projection based on an estimate of export-import trade was considered optimistic.

The four projections varied considerably by the end of the time frame of the forecast – the year 2000. They varied from a low forecast of 62 million tons to a high forecast of 97.7 million tons by the year 2000. Subsequent history has proved that all the projections fell considerably short of forecasting the increasing growth of canal traffic. The highest estimate of commercial cargo tonnage for the year 2000 was exceeded in FY 1969. Table III-1 depicts the degree of shortfall in the forecast.

Consideration was given to the matter of vessel transits although the study concentrated on cargo tonnage. By the year 2000, average cargo per transit was projected at 6600 tons. This produced a transit figure of 13,078 by the year 2000, utilizing the economic-statistical estimate of 86,312,000 net tons of commercial ocean traffic. The estimated year 2000 forecast of 13,078 net tonnage type commercial ocean traffic transits was surpassed in FY 1968 when 13,199 of this type of transit occurred. The average commercial cargo per ocean-going transit in FY 1969 amounted to 7,710 tons.

Certain assumptions were of significant importance to the study's resulting low estimates. The assumption which held petroleum traffic at the 1936 level, or at approximately 4 million long tons, was in error. In FY 1969, petroleum movements amounted to 17.6 million long tons. The impact of the world's rapidly expanding population on trade demand, and hence on canal traffic, was not considered. Productivity increases and Japanese post-war economic recovery were not anticipated.



COMPARISON OF PREVIOUS PANAMA CANAL TRAFFIC FORECASTS AND PANAMA CANAL ACTUAL TOTAL CARGO TONNAGE EXPERIENCE

FIGURE III-1

TABLE III-1

COMPARISON OF TRAFFIC PROJECTIONS (ISTHMIAN CANAL STUDIES – 1947) WITH ACTUAL EXPERIENCE

	Year 2000 Tonnage Forecast	Actual Commercial Ocean Traffic Tonnage
Panama Canal Trend (with Suez)	62,000,000	63,669,738 (FY 1961)
Panama Canal Trend	66,000,000	67,524,552 (FY 1962)
Economic-Statistical Projection (based on national income estimate)	86,312,000	96,550,165 (FY 1968)
Economic-Statistical Projection (based on export-import estimate)	97,700,000	101,391,132 (FY 1969)

Stanford Research Institute Studies Conducted for the Panama Canal Company

During the period 1958 through 1967 various studies were completed under contract for the Panama Canal Company by the Stanford Research Institute. The first in the series of studies, conducted in 1958, consisted of an analysis of future commercial ocean traffic through the Panama Canal. The second in 1960 consisted essentially of an updating of the 1958 study in the light of the intervening years of experience. A third study effort was conducted in 1964 in response to the need for a series of long-range projections of canal traffic. The final traffic projection study, completed in 1967, was part of an overall tolls sensitivity study. Although these studies were conducted within the short time span of nine years, each succeeding study resulted in upward revision of the cargo projections contained in the previous study. This was due to the inherent difficulty in making forecasts of this nature and to basic flaws in at least the first three projections. The cargo projections embodied in the first three study efforts have been too conservative. The Panama Canal Company's latest available statistics indicate that the fourth study has resulted in an overly conservative forecast of cargo – at least for the first target year of the forecast period. The four study efforts and a comparison with Panama Canal traffic experience are summarized in the following pages.

An Analysis of Future Commercial Freight Traffic Through the Panama Canal (Stanford Research Institute – 1958)

This Study formed part of the supporting documents for two larger canal studies: The *Bonner Report*, prepared for the House of Representatives by the Board of Cons ..ants,

Isthmian Canal Studies, June 1, 1960, and the report of the *Panama Canal Company Isthmian Canal Plans – 1960.* The methodology was disaggregative and an evaluation was made of the future trends of the elements of the activity; the evaluations were then summed for a projection of the total. This Study, like the 1947 Kramer Study, comprised a projection of commercial ocean traffic, but not total canal traffic (which includes the following Panama Canal Company categories: U.S. Government Ocean Traffic, Free Ocean Traffic, and traffic under 300 net tons, Panama Canal measurement).

The methodology employed analyzed previous canal traffic data to determine changes in cargo movements on the principal trade routes, and in the tonnage of important commodities shipped through the canal. A detailed study of trade routes, individual traffic components, and commodities was undertaken to analyze changes, and to estimate future traffic. Capacity of basic vessel types used to carry specific cargoes was examined to estimate the number of canal transits required to move the forecasted tonnage.

Subsequent history has proved that the projections were inaccurate on the low side. The projections of commercial ocean traffic, as compared with Panama Canal actual experience, are as follows:

Year 1975*		Year 2000		Actual-FY 1969	
Cargo Tonnage Estimate	Transit Estimate	Cargo Tonnage Estimate	Transit Estimate	Cargo Tonnage	Transits
73,436,000	11,530	102,130,000	15,452	101,391,132	13,150
Long Tons		Long Tons		Long Tons	

*The 1975 commercial ocean cargo tonnage projection was exceeded by FY 1965 when commercial ocean cargo tonnage amounted to 76,573,071 long tons. The 1975 transit projection was surpassed in FY 1964 when 11,808 commercial ocean transits were registered.

Basically, the disaggregative approach employed in the Study resulted in overly conservative forecasts in both cargo tonnage and transits. A major deficiency in the forecast was the fact that it overestimated the importance of ores and coal, and underestimated quantities of petroleum and petroleum products, phosphates, grains (other than wheat), and fishmeal. The failure to forecast the growth in petroleum and petroleum product traffic was particularly significant. Total petroleum cargo tonnage was estimated at 6.25 million long tons by 1975 and 6.9 million long tons by 2000. Actual petroleum cargo during FY 1969 amounted to 17,623,000 long tons.

The Addendum to an Analysis of Future Commercial Freight Traffic Through the Panama Canal (Stanford Research Institute – 1960)

In 1960, the Panama Canal Company asked the Stanford Research Institute to review its 1958 Study in the light of the intervening experience. A comprehensive revision was not attempted, and attention was focused only on those developments since the 1958 report which would suggest basic changes. The actual traffic, over the period FY 1958 through the Third Quarter FY 1960, was compared with the predictions of the earlier study. Variations were found both in the commodity tonnage movements and in the relation between the

commodity tonnage and the general cargo vessel transits. The revisions were limited to the nearer target date of 1975, with the projection of the earlier study for the year 2000 remaining unchanged. Commercial ocean traffic cargo tonnage for 1975 was raised from 73,436,000 long tons to 83,986,000 long tons. The transit projection for 1975 was increased from 11,530 to 14,115, reflecting increases in ore and general cargo transits.

The revised projections were no more accurate than their predecessors. By FY 1967 (less than half the projected period), the tonnage total had been exceeded. While the transit figure has not been equalled, this cannot be attributed to the accuracy of the projection, but rather to an increase in average ship size beyond that utilized in the Study. The revision repeated a major weakness of the earlier Study: overestimation of ore cargo and underestimation of petroleum traffic.

Stanford Research Institute Report of 1964

This Study was prepared in response to the need for a series of long-range projections of canal traffic. Forecasts were based on the disaggregative commodity approach; milestone dates of 1980 and 2000 were selected. The overall methodology was similar to that employed in the 1958 Study: commodity cargo was projected, and the number of transits was derived by applying estimated ship capacity to the commodities. More commodity groups were analyzed in detail in this Study. Although U.S. Government Ocean Traffic and Free Ocean Traffic were added to this Study, only Commercial Ocean Traffic was projected for the two target dates. Total commercial tonnage was estimated at 105,895,000 long tons for 1980, and at 152,775,000 long tons for 2000. Commercial cargo transits were projected to be 14,354 for 1980 and 18,263 for 2000.

The tonnage projections appear to be inaccurate – at least for the year 1980. Although the Study projected only two target dates, an indication of how well the projections compare with experience can be gained by comparing actual data since FY 1964 with values for the Fiscal Years 1964 - 1969, inclusive, taken from the line connecting the values predicted for 1980 and 2000, extended backward to FY 1964.

Comparison of Projections to Actual Commercial Cargo (millions of long tons)

FY	Projection	Actual
1964	68	70.5
1965	71	76.6
1966	73	81.7
1967	75	86.2
1968	78	96.5
1969	82	101.4

The transit projections – at least for the near-range – appear to be much more accurate. However, this results from both the underestimation of cargo tonnage and an underestimation of average ship size.

Stanford Research Institute Analysis of Panama Canal Traffic and Revenue Potential – 1967

The final traffic projection study in the series of studies conducted by the Stanford Research Institute was prepared in conjunction with a tolls sensitivity study conducted for the Panama Canal Company. This summary relates to the traffic projection portion of the Study. The time frame extended from 1967 to 1990 and resulted in projections of Commercial Ocean Traffic for the target years of 1970, 1980, and 1990. Like its predecessors, the Study followed the disaggregative commodity approach but embodied the most comprehensive research project yet undertaken by the Stanford Research Institute. Following completion of the 1964 estimates, it had become apparent that past projections had not considered adequately "new" commodities or new movements of existing commodities. The commodity-by-commodity approach had failed to consider changes and innovations in commercial traffic; therefore, a "new commodity movements" category was created.

Some eighteen categories or commodity groups were analyzed and totalled for the three target years. The projected Commercial Ocean Traffic cargo tonnages are shown below:

Millions Long Tons		
1970	**1980**	**1990**
94	113	140

The increases and decreases of each commodity group's cargo tonnage at the estimated target dates provide a view of the dynamics of projected tonnage growth. It also facilitates the location of discrepancies which may develop in the future. Table III-2 covers each commodity group for each target year and shows a comparison with actual experience in FY 1969.

It is already apparent that this Study has underestimated the growth of traffic through the Panama Canal. The forecast of 93,985,000 long tons of commercial cargo in 1970 was surpassed in FY 1968 with 96,550,165 long tons of this category of cargo and further exceeded in FY 1969 with 101,391,132 tons. This is due primarily to the continued surge in recent years of the growth of shipments of coal and coke from the East Coast of the United States to Japan as well as the continued closure of the Suez Canal. A cursory examination of Table III-2 reveals understandable variation between the 1970 projections of commodity movements and FY 1969 experience. This only serves to illustrate the inherent pitfalls in the disaggregative, commodity-by-commodity approach in making forecasts of traffic movements. Economic history is replete with examples of failure to anticipate dynamic forces and trends that have caused considerable alteration within the short span of a few years of commodity movements in world trade. At the same time history has proven that overall economic growth, including world trade, has continued at a fairly uniform rate. This basic circumstance has characterized the history of the growth of Panama Canal traffic.

TABLE III-2

COMMODITY PROJECTIONS (SRI-1967)
(000 Long Tons of Cargo)

Commodity	Actual 1969	1970	1980	1990
Petroleum and Products	17,623	16,000	15,475	14,970
Coal and Coke	16,291	6,700	8,150	9,600
Iron Ore	3,054	8,200	8,850	9,500
Sugar	3,642	4,285	4,770	5.300
Bananas	1,254	1,500	2,300	3,000
Coarse Grains	4,927	4,900	7,000	9,800
Soy Beans	2,552	2,600	3,000	4,500
Lumber	4,951	4,100	4,150	4,300
Bauxite-Alumina	1,353	1,200	1,450	1,700
Phosphate Rock	4,755	3,500	3,500	4,000
Wheat	1,675	2,600	4,200	6,300
Scrap Metal	2,673	2,500	2,000	1,500
Wood Pulp and Paper	2,622	2,000	3,400	5,900
Rice	875	800	1,300	1,800
Nitrogenous Products	3,455	2,800	3,000	3,500
Sulfur	369	900	1,200	1,800
General Cargo	29,320	27,000	30,000	35,000
New Commodity Movements	–	2,400	9,100	17,000
TOTAL	101,391	93,985	112,845	139,470

Gardner Ackley Projection of Traffic Through the Panama Canal in Relation to Canal Capacity – 1961

In 1961, Mr. Gardner Ackley, an economist serving at the time as a consultant to the Secretary of the Army, prepared a memorandum for the Secretary in which he discussed and illustrated several possible methods of projecting traffic through the Panama Canal and then made some projections of his own in terms of future numbers of transits which he considered to be conservative, minimum estimates. Mr. Ackley discussed and rejected the "commodity-by-commodity, country-by-country" approach that had been employed by the

Stanford Research Institute in its 1958 Study. He felt that this approach was restricted by concentration on traffic movements of current importance without proper consideration being given to future growth possibilities, especially with respect to the economic growth of aggregate production in the countries involved in such an analysis. Other approaches discussed by Mr. Ackley included a straight-line projection of trend (based on an analysis of Panama Canal traffic during the post-World War II era), and an econometric projection (which uses economic theories about causative factors in economic growth, measures their past influence by statistical methods, and assumes that factors demonstrating a stable relationship in the past will continue to do so in the future).

Mr. Ackley estimated that there would be 17,000 transits in 1975 and 30,000 in the year 2000. He regarded these as "minimum safe planning figures" and felt that they were definitely on the conservative side. He used the straight-line trend projection method based on a constant incremental increase in absolute amounts of transits rather than a constant percentage rate. He felt that use of a constant exponential growth rate applied to transits would have resulted in "fantastic" numbers and would have ignored the offsetting effects of larger average ship sizes in the future. His estimate of 30,000 transits in the year 2000 was related to an estimate of optimum canal capacity of a like quantity of transits. This is higher than current estimates of canal capacity without major modification. However, in the light of Panama Canal transit experience since 1960 Gardner Ackley's aggregative type estimates of transits are quite realistic.

Conclusion

This summary of previous Panama Canal studies serves to illustrate the inherent difficulties involved in estimating future demand for interoceanic commercial transportation through an Isthmian canal, especially for any considerable period into the future. As Gardner Ackley pointed out in his 1961 examination of this matter, "Panama Canal traffic is an aggregate of intermediate scope. It is composed of many specific currents that may rise and fall, and which are likely to be at least partially offsetting in their effects. On the other hand, canal traffic is not merely a microcosm of total economic activity; it is dominated by a relatively small number of important commodities, mostly the raw materials or products of a few industries. Further, because it depends on economic developments in a number of separate countries, many of which are in early and uncertain states of evolution into modern economic organization, its projection is more difficult than that of an activity confined to a single, already-developed economy whose future course is more predictable."

The traffic projections contained in previous studies, although resulting from intensive research by competent individuals and organizations, failed to provide an accurate forecast of the increasing growth of canal traffic for the reasons cited in this summary. They were invariably low and overtaken by events within a relatively short span of time after the date of the forecast. They were predicated, in large part, on the disaggregative, commodity analysis approach and failed to provide allowance for the dynamic, unpredictable factors that influence constant world economic growth and advances in international trade. The forecasts applied to the existing lock canal only and were acceptable for short-term financial planning by the Panama Canal Company. Analysis of the traffic projection results of these studies demonstrates clearly the need for a different approach in estimating and planning future capacity requirements and potential sea-level canal traffic.

Chapter IV

ISTHMIAN CANAL TRAFFIC FORECAST

Introduction

A long-range forecast of potential Isthmian canal traffic is needed for three purposes:

a. To predict the date at which the present Panama Canal cannot accommodate the total number of ships requiring transit.

b. To determine the canal capacity that will be needed in the future, both in channel dimensions and numbers of transits, if the future needs of world and United States interoceanic freight transportation are to be met.

c. To estimate the tolls revenues that could be available over the long term to repay investment in new capacity.

It is the consensus of those engaged in economic research that the reliability of forecasts of economic activities decreases rapidly as their time span increases. Most canal users invest in ships and other resources on the basis of forecast demands no more than twenty years into the future. A new sea-level canal, however, could not be in operation for fifteen years or thereabouts, and at least fifty more years should be available for its amortization. As the present worth of future revenues beyond the year 2040 is not of great significance to a current determination of the financial feasibility of a new canal, the Commission directed the Shipping Study Group to develop estimates of potential canal cargo tonnages, transits, and revenues for the period 1970 through 2040. The Commission further directed that the Study Group forecast the range of future traffic possibilities with the objective of establishing a reasonable planning goal for which capacity should be provided. A potential tonnage forecast was developed which defines a transit range dependent on ship cargo mix and maximum vessel size to be accommodated.

The quality of any forecast of economic growth depends on an understanding of the factors of causality that operate to expand and constrain growth. As discussed in Chapter III, most previous Panama Canal traffic forecasts utilized a technique of commodity analysis, commonly called disaggregation, to determine causality; here, the growth-maturation-stagnation cycle of each commodity is employed to develop a total of commodity tonnage through the canal. While this type of forecasting technique is undoubtedly useful for short-range planning purposes, it is of marginal value for estimating Isthmian canal traffic for the next seventy years. Potential movements of individual commodities are affected by many variables, and most are subject to changes that are unpredictable for more than a very few years in advance. The history of the growth of Panama Canal traffic to new peaks has been essentially that of the continued emergence and rapid growth of new traffic patterns, while earlier components have, in the aggregate, grown less rapidly. The influence of new commodity development (not accounted for in

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disaggregation) is increasingly important as the target forecast year is extended because existing commodities generate proportionally less tonnage as they achieve the maturity phase in the growth cycle. Thus, the experience of forecasting efforts to date has shown that a commodity-by-commodity approach inevitably has downward bias and results in forecasts that are conservative.

The converse of this approach, called aggregation, involves the projection of growth trends of gross aggregates of economic activity usually along exponential lines. New commodity development is implicitly included, but the resultant forecast may yield growth patterns of skyrocketing proportions.

Panama Canal traffic growth is influenced both by the evolution of individual economic cells, and by the general exponential trend reflected in world trade and economic expansion. It is stimulated by economic growth, but also influenced by shifts in regional economic maturity levels and the spacial and dynamic economic relationship of one region to another. While a growth in regional Gross National Product (GNP) generates an increase in tonnage exports that may transit the canal, an increase in per capita GNP (indicating an advance in industrial maturity) encourages vertical and horizontal domestic economic integration and tends to deemphasize the raw material extractive industries which reduces the incremental growth in tonnage exports. Trade patterns that determine canal usage are specified by economic and geographic interrelationships.

Methodology

In view of the foregoing basic considerations, the potential tonnage forecast to the year 2000 is predicated essentially on an aggregative approach with emphasis on the relationship between interoceanic canal trade and economic development of the regional areas which contribute to this trade. Beyond the year 2000, the potential tonnage forecast was projected to the year 2040 by total aggregation, reducing the rate of growth existing at year 2000 to zero growth at year 2040 in equal, yearly decrements over the forty years. The "bending down" of the rate of growth in the Twenty-First Century resulted basically from inability to forecast world trade from 30 to 70 years into the future; thus a conservative growth estimate was assumed for this period. The potential tonnage forecast is the basic forecast of this study.

The potential tonnage forecast for canal traffic is made in terms of projections of total potential annual cargo tonnage. The next step in the overall process of projecting traffic is to determine the sizes and distribution of ships that would transport the potential cargo tonnage. For this purpose the world's merchant fleet is divided into three general classes: tankers, dry bulk carriers, and freighters. Each class of ship has a set of identifiable operating characteristics in Isthmian canal trade, including size distribution. Projections of the sizes and size distribution of the world fleet are provided. The world fleet size distribution is modified to reflect the size distribution experience of the present Panama Canal and the constraints of the canal configuration under consideration, i.e., maximum ship size accommodated. From the resulting Isthmian canal ship size distribution, the projected average ship for each ship class is identified. The potential cargo tonnage is assumed to be carried on these average ships for the purpose of computing numbers of transits expected in the future. Plans for world-wide harbor and port development are

examined in connection with the foregoing analysis of oceanborne and interoceanic canal shipping trends.

The total potential annual cargo tonnage is apportioned among the three classes of ships. The percentages assigned define the cargo mix, i.e., the per cent of total potential tons carried by each ship type. The selected cargo mixes are based on recent Panama Canal experience. The final factor to be considered is the relationship between cargo tonnage and ship capacity (DWT). For this purpose, a ship efficiency index has been defined as the ratio of cargo tons to deadweight tons. This index is a unique characteristic of each class of ship in Isthmian canal trade, and inherently accounts for transits in ballast, partially laden ships, and cargo density.

Using the factors of cargo mix, ship efficiency index, and average DWT, the total potential annual cargo tonnage is translated into total annual transits required. The total annual tonnage actually transited equals the potential tonnage until the transit capacity of any canal option is reached. Thereafter, the tonnage increases very slowly, as only the average size of ship increases and the number of annual transits remains essentially constant. The revenues produced are computed from the annual tons transited and the average toll per cargo ton. This calculation is carried out separately for each class of ship since each has different average tolls per ton as computed from Panama Canal experience. (Canal tolls are assessed on earning space, not cargo tons.)

The methodology for forecasting Isthmian canal traffic is explained further and illustrated in subsequent portions of this Chapter and Chapter V, Potential Revenue for Use of a Sea Level Canal, and described in detail in Appendix 1, Methodology for Computation of Projected Canal Traffic and Revenues.

Economic Considerations

World and United States Economic Growth and Oceanborne Trade

Economic Growth and Oceanborne Trade

The annual rate of growth of the total world economy since 1948 has been calculated by the United Nations to have been 4.4 percent in constant dollars. Data for longer periods are less exact, but world economic growth appears to have stayed consistently in the narrow range of 3 percent to 5 percent annually for the past 100 years. The United Nations forecasts that world economic growth will continue in the future at the 4.4 percent rate as a minimum. United States economic growth is expected to increase at approximately the same rate. Continued economic growth at these proportions will exert a major influence on the continued growth of oceanborne trade and the Isthmian Canal portion of this trade.

Table IV-1 shows the growth of world oceanborne trade by major geographic areas from 1938 through 1966. Based on available data, the United Nations estimates that this trade increased to approximately 1,860 million metric tons in 1967. In the same year, the volume of U.S. oceanborne trade amounted to 387,568,000 long tons. Table IV-2 summarizes the dynamic structure of oceanborne trade by type of cargo for the period from 1937 to 1966.

During the period 1948-1967 world oceanborne cargo tonnages have grown at an average annual rate of 7.2 percent and are forecast to continue at approximately the same rate. From 1960 to 1967 the average annual growth rate of the main bulk commodities and

TABLE IV-1

WORLD OCEANBORNE TRADE

(Goods Loaded (A) and Unloaded (B) in External Trade)

Year	World Total[1]	Africa A	Africa B	North America A	North America B	South America A	South America B	Asia A	Asia B	Europe A	Europe B	Oceania A	Oceania B	U.S.S.R. A	U.S.S.R. B
	Million Metric Tons														
1938	470	28	23	108	81	52	19	84	68	185	266	8	9	9	1
1948	490	31	27	160	151	98	29	84	50	108	226	7	9	(.)[2]	(.)
1953	680	41	34	167	211	121	29	170	93	173	305	11	14	(.)[2]	(.)
1958	940	53	45	210	260	181	38	276	147	184	430	13	22	22	4
1959	990	57	51	210	288	196	38	298	148	187	440	16	22	30	5
1960	1,110	70	54	227	290	209	37	335	181	209	511	18	25	39	6
1961	1,180	83	56	239	288	209	37	365	215	213	533	22	28	51	7
1962	1,280	98	58	260	317	225	36	398	233	216	594	25	27	60	7
1963	1,380	125	61	286	326	229	35	427	258	224	654	24	30	67	9
1964	1,550	168	67	316	352	247	40	486	303	236	727	30	33	71	12
1965	1,670	195	73	321	378	263	42	527	341	256	791	30	36	79	13
1966[3]	1,790	224	76	335	389	262	[illegible]	582	378	269	838	32	38	90	12

[1] Total tonnage loaded which, after adjustment for time lag, is approximately the same as the total tonnage unloaded in any year.

[2] 1948 and 1953 estimates for U.S.S.R. are included with data for Europe.

[3] Provisional.

SOURCE: United Nations Statistical Yearbook, 1967, New York, 1968, page 77

other dry cargo was 6.6 percent for the former and 6.1 percent for the latter. During the same period the average annual rate of growth of petroleum loadings was 13.4 percent. The trend toward a greater share for petroleum (tanker cargoes) in total world movements has continued to rise rapidly. The share of petroleum comprised 21 percent of total oceanborne tonnage in 1937, represented 50 percent in 1960 and rose to 56 percent in 1967.

A recent forecast of world oceanborne trade based on world trends and expectations is projected in Figure IV-1. This forecast was based, in part, on a forecast made

by the United Nations Conference on Trade and Development (UNCTAD) in a study of world petroleum movements. It predicted a probable slackening in the world demand for petroleum, hence a shift in tanker tonnage resulting in dry cargo again becoming the dominant segment of oceanborne trade early in the Twenty-First Century.

The Panama Canal's portion of total world oceanborne cargo movements each year has remained remarkably consistent. Table IV-3 shows a comparison between Panama Canal Total Ocean Traffic and world oceanborne trade for selected years 1938-1967. For the period 1958-1967 it has varied less than one percentage point above or below 5.1 percent of the world total.

The World Merchant Fleet

While the growth in the value and volume of world trade may be attributed to many factors such as the rise in industrial production creating an almost insatiable demand for raw materials, improvements in the means of transportation must also be considered among the most important factors. Progress in transportation epitomizes the development of the modern economy; the following considers the size and structure of the world's merchant marine since the vast majority of world trade is transported in oceanborne vessels.

TABLE IV-2

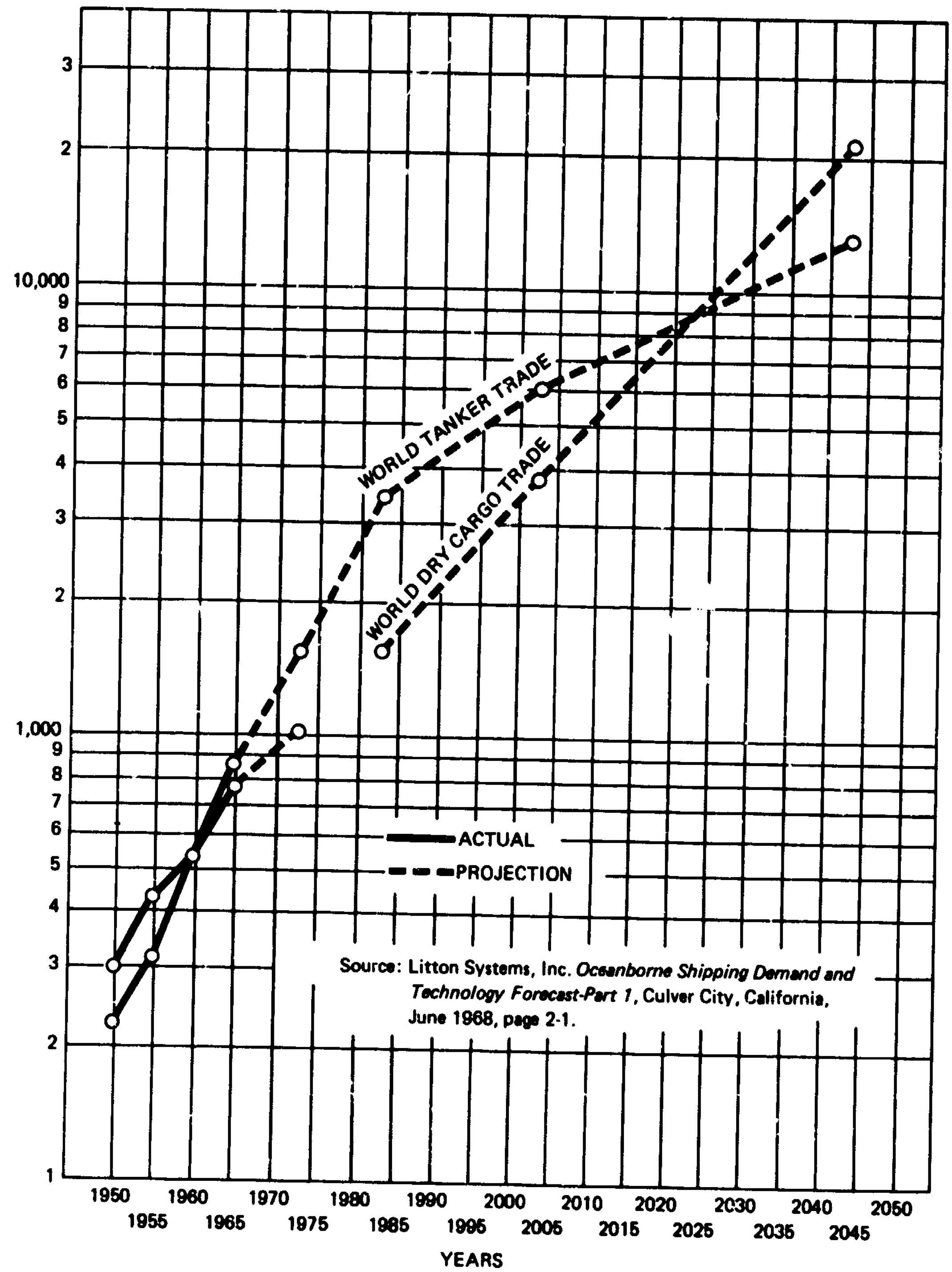
WORLD OCEANBORNE GOODS LOADED BY TYPE OF CARGO

Type of Cargo	1937	1958	1959	1960	1961	1962	1963	1964	1965	1966
	Million Metric Tons									
Ocean Shipping[1] Total	490	940	990	1,110	1,180	1,280	1,380	1,550	1,670	1,790
Tanker Cargo[2] Total	105	440	480	540	580	650	710	790	870	950
Dry Cargo Total	375	480	490	540	570	600	640	720	770	800

[1]Approximate figure that includes data on international cargoes loaded at ports of the Great Lakes and St. Lawrence system for unloading at ports of the same system and not included in the Tanker and Dry Cargo totals.

[2]Crude petroleum and petroleum oils; includes crude petroleum imports into Netherlands Antilles and Trinidad and Tobago for refinery and re-export.

SOURCE: United Nations Statistical Yearbook, 1967, New York, 1968, page 77



WORLD OCEANBORNE TRADE FORECAST

FIGURE IV-1

TABLE IV-3

COMPARISON OF WORLD TONNAGE AND PANAMA CANAL TONNAGE

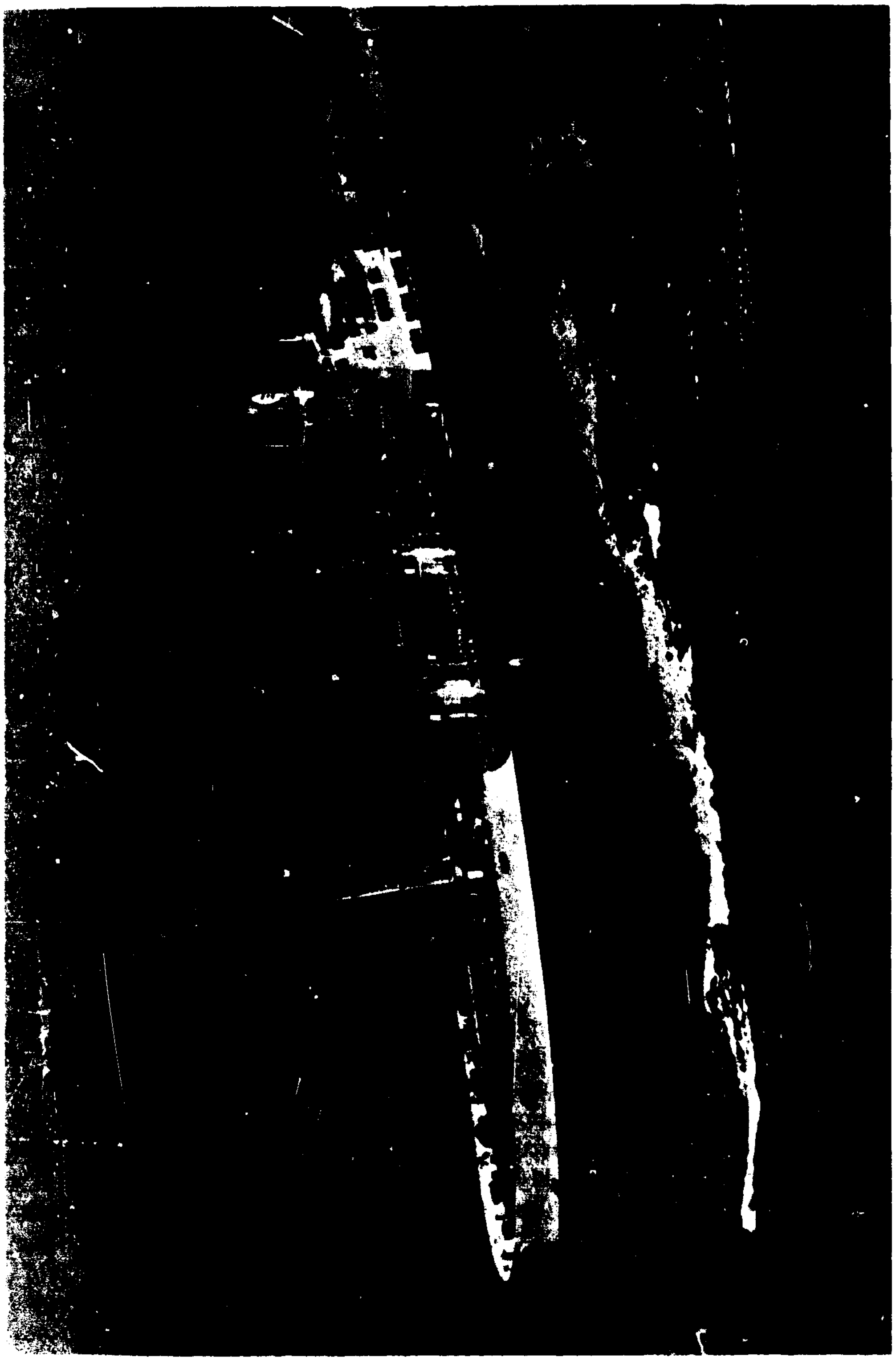
SELECTED YEARS 1938-1967

Year	World Tonnage (Million Metric Tons)	Panama Canal Total Ocean Traffic (Million Long Tons)	PC WT %
1938	470	27.5	5.9
1948	490	25.6	5.2
1958	940	49.0	5.2
1959	990	52.3	5.3
1960	1,110	60.4	5.4
1961	1,180	65.2	5.5
1962	1,280	69.1	5.4
1963	1,380	63.9	4.6
1964	1,550	72.1	4.7
1965	1,670	78.9	4.7
1966	1,790	85.3	4.8
1967[1]	1,860	93.0	5.0

[1] Provisional

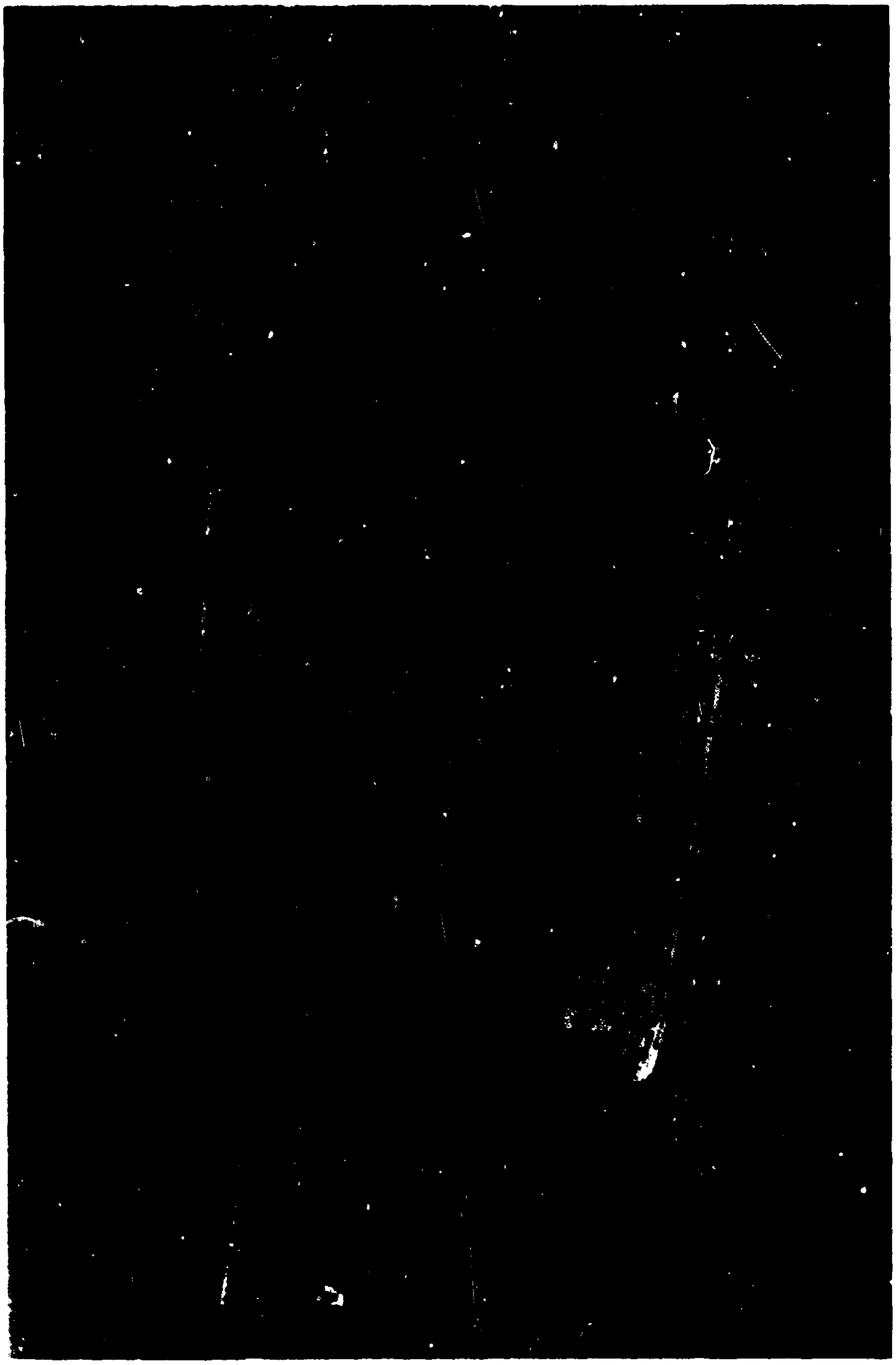
SOURCE: United Nations Statistical Yearbook, 1967
Panama Canal Company Annual Reports

On December 31, 1968, the world's merchant fleet of oceangoing ships, 1,000 gross tons and over, totaled 19,361 ships of 273.2 million deadweight tons. Table IV-4 depicts the growth of the world merchant fleet during the period 1949-1968. Total world tonnage increased during this period approximately 164 percent. Table IV-5 shows the twelve major maritime fleets, which accounted for more than 82 percent of the total deadweight tonnage comprising the world fleet on December 31, 1968. Liberia ranked first among the maritime nations of the world and 45.1 million deadweight tons registered under her flag represented 16.5 percent of the world total. Norway and the United Kingdom which ranked second and third represented 11.2 percent and 11 percent of the world's deadweight tonnage, respectively. Japan, the fourth leading maritime nation, represented 10.7 percent of the world's carrying capacity. The United States, in fifth place, the only

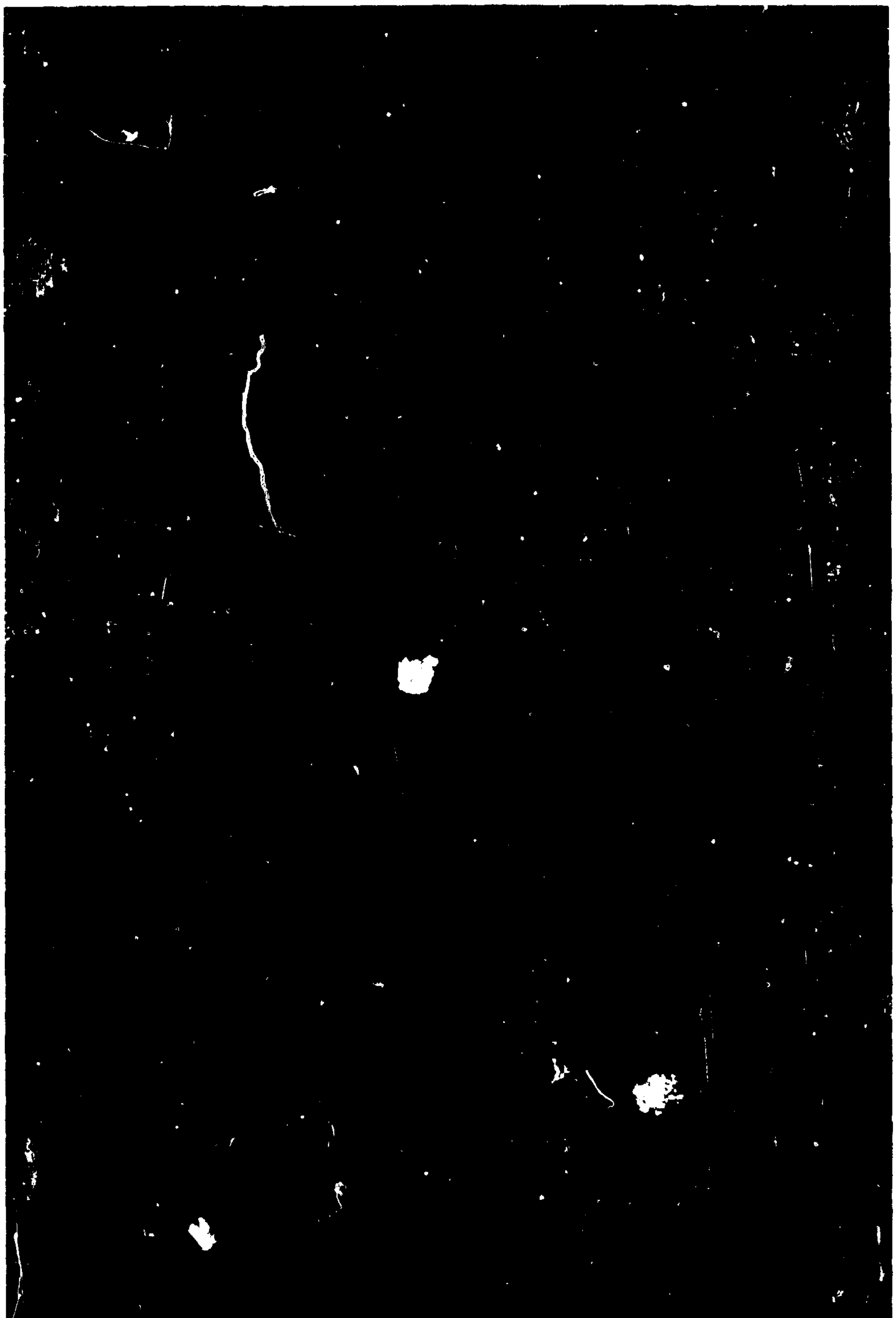


The S.S. ALASKAN MAIL, a freighter of the general cargo type

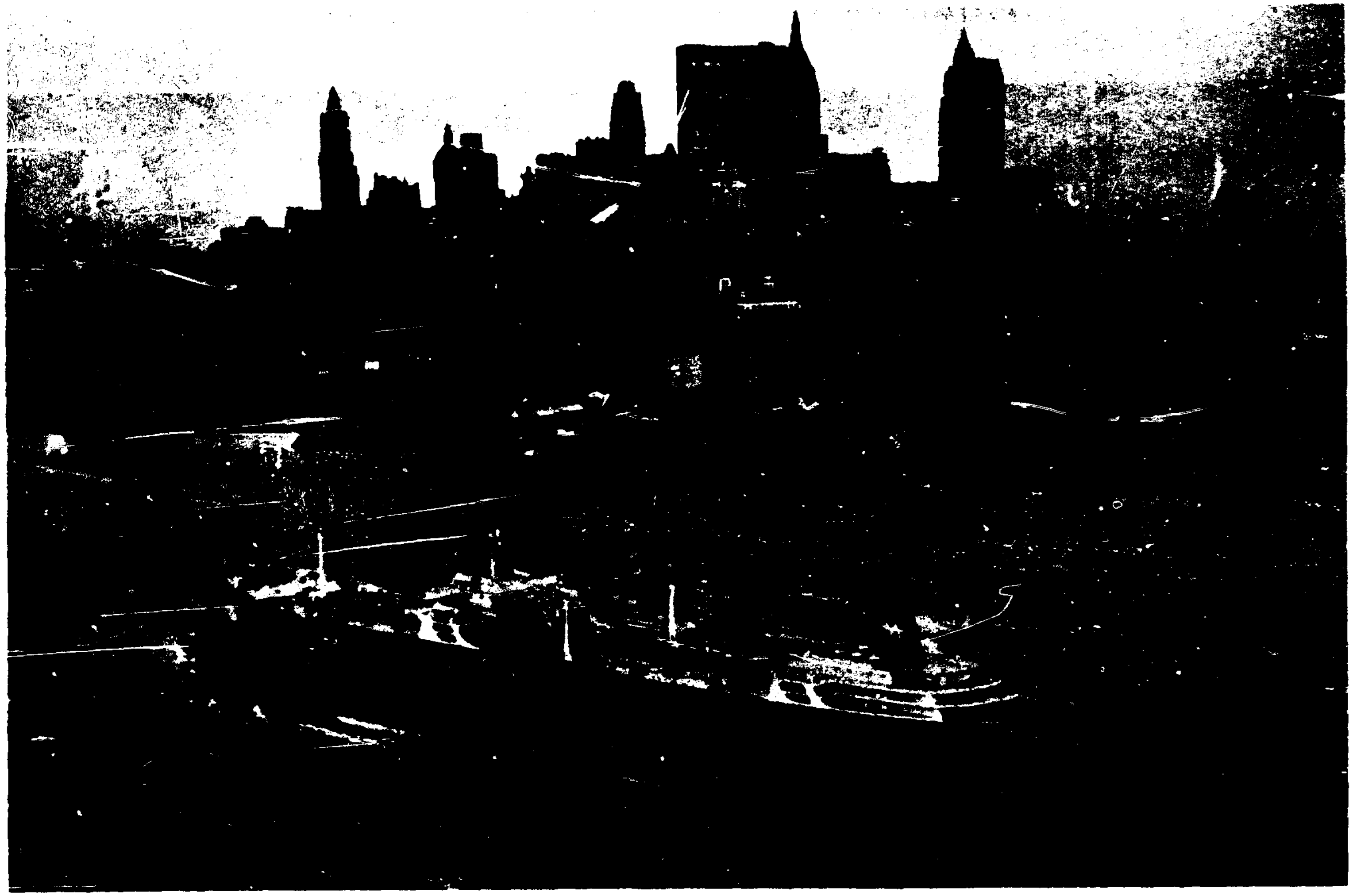
The S.S. MORMACSKY, a freighter designed for the carriage of containers and roll-on roll-off equipment



A containership of the SEALAND fleet used for the carriage of containers exclusively



The S.S. CEDROS, one of the world's largest bulk carriers with a capacity of 170,418 DWT



The S.S. MANHATTAN prior to conversion for Arctic work--the largest U.S. flag tanker with a capacity of 108,400 DWT

TABLE IV-4

GROWTH OF THE MERCHANT FLEETS OF THE WORLD (1949-1968)
OCEANGOING STEAM AND MOTOR SHIPS OF 1,000 GROSS TONS AND OVER
(Tonnage in Thousands)

Year	Total			Freighters[1]			Bulk Carriers			Tankers (Including Whaling Tankers)		
	Number	Gross Tons	Dead-Weight Tons	Number	Gross Tons	Dead-Weight Tons	Number	Gross Tons	Dead-Weight Tons	Number	Gross Tons	Dead-Weight Tons
1949	12,868	73,640	103,461	10,287	56,031	76,370	559	1,764	2,829	2,022	15,845	24,263
1950	13,282	75,718	107,461	10,583	56,921	78,123	561	1,702	2,776	2,138	17,095	26,318
1951	13,646	78,821	110,655	10,809	58,509	79,414	572	1,782	2,832	3,365	18,530	28,409
1952	14,019	81,924	114,946	11,034	59,864	80,945	576	1,851	2,912	2,409	20,269	31,089
1953	14,370	85,102	119,427	11,226	60,724	82,125	593	1,988	3,107	2,551	22,390	34,195
1954	14,793	89,258	124,754	11,483	62,240	83,476	614	2,214	3,455	2,696	24,804	37,823
1955	15,148	92,944	129,975	11,736	63,931	85,715	653	2,628	4,081	2,759	26,385	40,179
1956	15,615	97,665	136,880	12,077	66,232	88,822	704	3,246	5,122	2,834	28,187	42,936
1957	16,293	104,770	147,316	12,512	69,176	92,826	763	3,880	6,111	3,018	31,714	48,379
1958	16,966	112,314	158,047	12,869	71,551	95,603	868	4,997	7,764	3,229	35,766	54,680
1959	17,185	117,640	166,014	12,802	71,420	95,105	1,016	6,661	10,269	3,367	39,559	60,640
1960	17,317	122,027	171,890	12,766	71,988	95,159	1,185	8,461	12,984	3,366	41,578	63,747
1961	17,426	125,851	177,290	12,705	72,075	94,947	1,349	10,476	15,971	3,372	43,300	66,372
1962	17,861	132,064	185,843	12,861	73,474	96,065	1,592	13,171	19,907	3,408	45,419	69,871
1963	18,333	137,657	194,274	12,871	74,014	96,352	1,726	15,750	23,832	3,436	47,893	74,090
1964	18,115	143,675	204,154	12,810	73,935	96,058	1,822	17,337	26,354	3,483	52,403	81,742
1965	18,329	151,868	217,229	12,776	74,140	95,975	1,971	20,696	31,531	3,582	57,032	89,723
1966	18,423	161,006	232,197	12,666	74,480	95,993	2,103	24,618	37,970	3,654	61,908	98,234
1967	18,800	171,522	250,403	12,692	74,074	95,223	2,368	31,644	49,638	3,740	65,804	105,542
1968	19,361	184,242	273,210	12,857	75,005	96,149	2,609	37,596	59,926	3,895	71,641	117,135

Notes: Excludes ships operating exclusively on the Great Lakes and inland waterways and special types such as channel ships, icebreakers, cable ships, etc., and merchant ships owned by any military force.

[1] Includes following categories: freighters, combination passenger and cargo, combination passenger and cargo refrigerated, and freighters refrigerated.

SOURCE: U.S. Department of Commerce, Maritime Administration

TABLE IV-5

TWELVE MAJOR MARITIME FLEETS OF THE WORLD

December 31, 1968

(On the Basis of Deadweight Tonnage)

1968 Rank	Country	Number of Vessels	Gross Tons (000)	Deadweight Tons (000)	Recent Trends in DWT Rank 1967	1966	1965	1964
1	Liberia	1,613	26,984	45,141	1	1	1	3
2	Norway	1,308	19,231	30,593	2	4	4	4
3	United Kingdom	1,840	20,845	29,917	3	3	3	2
4	Japan	1,766	18,797	29,222	5	5	5	5
5	United States[1]	2,071	18,675	25,464	4	2	2	1
6	U.S.S.R.[2]	1,634	9,457	11,911	6	7	6	7
7	Greece	1,006	7,890	11,543	7	6	7	6
8	West Germany	909	6,399	9,320	8	8	9	9
9	Italy	620	6,266	8,686	9	9	10	8
10	Panama	623	5,165	8,009	10	10	8	10
11	France	485	5,414	7,618	11	11	11	11
12	Sweden	408	4,660	6,945	12	A	A	A
13	All Other	5,078	34,459	48,841	–	–	–	–

[1] The privately owned United States Merchant Marine includes only 967 vessels totalling 10,649,000 gross tons and 15,346,000 deadweight tons. The above figure reflects the Government-owned Reserve Fleet and those vessels operated under general agency agreement, bareboat charter and in the custody of the Department of Defense, State and Interior.

[2] Source material limited.

A. Netherlands ranked twelfth in 1966, 1965 and 1964.

SOURCE: U.S. Department of Commerce, Maritime Administration

country among the major maritime nations to show an almost continuous decline in the last two decades, represented only 5.6 percent.[1]

Table IV-6 depicts the trend in deadweight percentage distribution of the world fleet by vessel class during the period 1961-1968. It shows that the bulk carrier is the fastest

[1] This figures includes only the U.S. privately-owned fleet. It excludes the National Defense Reserve Fleet which comprised more than 8.3 million deadweight tons as of December 31, 1968. Other U.S. owned vessels under general agency agreement, bareboat charter, or in the custody of the Department of Defense, State and Interior are also not included in this figure.

TABLE IV-6

DEADWEIGHT PERCENTAGE DISTRIBUTION OF THE WORLD FLEET BY VESSEL CLASS

Year	Total	Combination	Freighters	Dry Bulk Carriers	Tankers
1961	100	4	50	9	37
1962	100	3	48	11	38
1963	100	3	47	12	38
1964	100	3	44	13	40
1965	100	3	41	15	41
1966	100	2	39	16	43
1967	100	2	36	20	42
1968	100	2	33	22	43

SOURCE: U.S. Department of Commerce, Maritime Administration

growing class of ship. In 1968 tankers and dry bulk carriers made up 65 percent of the world fleet's deadweight carrying capacity in comparison with the 1961 total of 46 per cent for tankers and dry bulk carriers. Thus, there has been a dramatic structural change in the deadweight tonnage distribution of the world fleet by vessel class.

Isthmian Canal Trade

The history of Panama Canal traffic has been described briefly in Chapter II. The purpose of this section of the study is to present an analysis of the cargo portion of canal traffic experience covering the period since World War II. The requirements for new Isthmian canal capacity are based on projected increases in cargo tonnage that potentially would transit the canal. Such projections are based not only on the future outlook but on past experience in order to identify trends in the growth of cargo tonnage. "Tonnage transited" is emphasized in measuring overall potential canal demand because it is a better measure than "ships transited;" the latter criterion contains variations in size, capacity, and loading. However, for canal design purposes, it is essential to estimate the number of transits required to carry the potential cargo tonnage.

Panama Canal traffic can be subdivided into many categories for purposes of statistical analysis. The two major categories of traffic are Commercial Ocean Traffic and U.S. Government Ocean Traffic (ships owned by or operated under contract for the United States Government). The remainder of the traffic (identified by the Panama Canal Company as Free Ocean Traffic, Small Commercial Traffic, Small U.S. Government Traffic, and Small Free Traffic) do not contribute significantly to the total. Commercial Ocean Traffic represents the vast preponderance of cargo tonnage that transits the Panama Canal.

Commercial Ocean Traffic can be further subdivided and analyzed in several ways. These include classification by type of vessel, commodities shipped through the canal, and

origins and destinations of cargo shipments. Petroleum shipments have represented the most important single commodity shipments tonnage-wise for the last two decades.

Table IV-7 and Figure IV-2 depict Panama Canal cargo tonnage by category of traffic since World War II. The tanker cargo tonnage is identified separately to reflect trends in petroleum shipments. The remainder of the commercial ocean cargo tonnage was transited mostly in dry-bulk carriers and freighters.

The Panama Canal cargo tonnage history was examined for major trends and rates of growth. Analysis of canal statistics can produce varied results whether done by computer least squares analysis or by visual fitting; contradictory and misleading results are possible if the results are regarded as accurate to a fine degree. Table IV-8 is intended to be merely a gross indicator of traffic growth during selected periods, based on common use growth tables. It shows that the annual growth rate varies in accordance with the period selected for analysis. More sophisticated types of statistical analysis of the identical periods shown in the table will provide different results. Statistical data should be used, therefore, only in a general or gross manner as one of many guides of what may happen in the future.

In this study the method of least squares was used to quantify the trend analysis, the details of which are contained in Appendix 2, Analysis of Panama Canal Cargo Tonnage History. For the period 1947 to 1969, the total cargo tonnage has increased at a nearly uniform annual rate of approximately 6.5 per cent. The period 1964-1968 saw a significant rise in this rate. Some of this increase was due to traffic generated by the Vietnam conflict, some to the closure of the Suez Canal, and some to other factors. Considering only commercial ocean tonnage (essentially total tonnage less U.S. Government ocean tonnage), the apparent impact of Vietnam on the recent growth rate is reduced. However, due to inability to quantify that portion of commercial ocean tonnage generated by hostilities in Southeast Asia, the complete impact of Vietnam cannot be identified. The growth of commercial ocean tanker tonnage has been declining in recent years. Finally, the trend in the growth of trade with Japan demonstrates that this component is the current major contributor to the growth of Panama Canal cargo tonnage.

Principal Trade Routes

Table IV-9 shows 13 major Panama Canal trade routes ranked according to the long tons of commercial ocean cargo moving in both directions along these routes in Fiscal Year 1969. A comparison is made with the volume of commercial cargo movements along the same routes for the period 1965-1968 and selected earlier fiscal years.

Table IV-9 shows that the greatest increase by far in cargo tonnage movements along any single trade route is between the East Coast United States and Japan, increasing from approximately one-half million long tons of cargo in 1947 to almost 33 million tons in 1969. The vast bulk of this cargo has originated in the United States, amounting to over 27.3 million tons in 1969. In Fiscal Year 1969 the five principal commodities moving along the East Coast United States to Japan route in order of importance were coal and coke, phosphate, corn, scrap metal, and soybeans. The rapid growth in canal cargo shipments from the United States and other origins to Japan has been coincident with and was caused primarily by the tremendous expansion of the Japanese steel industry, which depends upon imports of raw materials, particularly coal and iron ore. It is doubtful that Japanese economic expansion can long continue at its phenomenal growth rate of recent years. There

TABLE IV-7

PANAMA CANAL CARGO TONNAGE BY MAJOR CATEGORY, 1947-1969 (000 Long Tons)

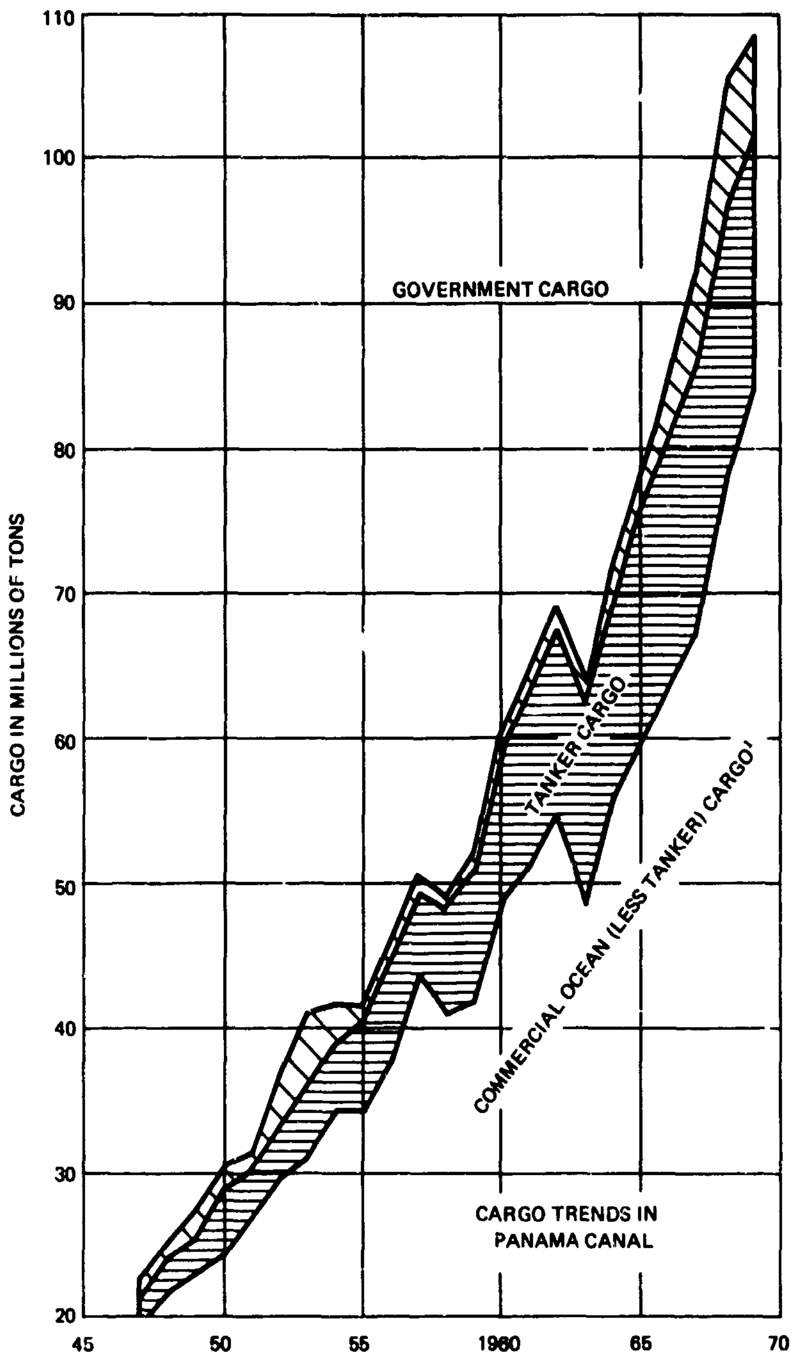
Fiscal Year	U.S. Govt. Ocean Cargo	Tanker Cargo	Commercial Ocean Less Tanker	Total[1] Cargo
1947	983.7	2,109.2	19,561.3	22,688.4
1948	1,520.6	2,297.2	21,820.6	25,664.2
1949	2,217.5	2,267.5	23,037.7	27,782.6
1950	1,429.3	4,571.4	24,300.9	30,365.0
1951	1,166.0	3,121.4	26,951.6	31,281.5
1952	3,237.3	3,802.9	29,807.6	36,902.9
1953	5,049.9	5,005.0	31,090.3	41,203.4
1954	2,708.4	4,632.1	34,463.0	41,882.4
1955	838.3	6,368.6	34,277.7	41,548.0
1956	1,150.1	7,165.5	37,953.5	46,331.9
1957	922.2	5,879.6	43,822.6	50,659.1
1958	791.3	6,956.4	41,168.4	48,982.0
1959	1,012.8	9,155.0	41,998.0	52,329.0
1960	804.6	10,450.3	48,807.9	60,401.7
1961	1,149.9	12,410.1	51,259.6	65,216.6
1962	1,126.4	12,693.4	54,831.2	69,063.5
1963	1,115.4	13,377.2	48,869.9	63,877.2
1964	1,177.3	14,247.2	56,302.9	72,168.7
1965	1,923.5	16,680.4	59,892.7	78,922.9
1966	3,220.2	17,904.1	63,799.4	85,323.5
1967	6,147.5	18,851.4	67,342.0	92,998.0
1968	8,497.2	17,941.7	78,608.5	105,538.3
1969	7,210.1	18,328.1	83,063.0	108,793.1

[1] Includes Free Ocean, Small Commercial, Small U.S. Government, and Small Free Traffic

SOURCE: Panama Canal Company Annual Reports

are also indications that the Japanese steel industry has taken effective steps to obtain requisite raw materials from the Pacific Basin, particularly from Australia. While Japan should continue to play an important role in Isthmian canal traffic for the foreseeable future, it could exert less of a predominant influence on the overall growth rate than it has in the past.

Cargo tonnage shipments along other trade routes involving Asia (primarily as a destination rather than an origin) have also demonstrated a high rate of growth since World War II. These include East Coast United States – Asia (less Japan) and West Indies – Asia.



[1] INCLUDES REMAINDER OF TOTAL TRAFFIC, i.e. ALL MINOR CATEGORIES (FREE AND SMALL TRAFFIC)

SOURCE: PANAMA CANAL COMPANY ANNUAL REPORTS

FIGURE IV-2

TABLE IV-8

GROWTH RATES, PANAMA CANAL TOTAL CARGO TONNAGE

Selected Years – Period 1915-1969
(000 Long Tons)

Year	Long Tons	Year	Long Tons	Number of Years	Annual Growth Rate (percent)
1915	4,937	1969	108,793	54	5.9
1915	4,937	1929	30,782	14	14.0
1915	4,937	1965	78,923	50	6.0
1920	9,731	1930	30,164	10	12.0
1920	9,731	1966	85,323	46	4.9
1929	30,782	1944	11,593	15	-7.0
1930	30,164	1950	30,365	20	0.0
1930	30,164	1965	78,923	35	2.8
1940	27,524	1966	85,323	26	4.4
1940	27,524	1969	108,793	29	4.9
1944	11,593	1969	108,793	25	9.3
1947	22,688	1969	108,793	22	7.4*
1948	25,664	1964	72,169	16	6.7
1948	25,664	1966	85,323	18	6.9
1948	25,664	1969	108,793	21	7.1
1949	27,783	1969	108,793	20	7.1

Note: Computations based on Tables for Rates of Growth and Rates of Decline, U.S. Department of Agriculture, June 1966.

*Computer least squares analysis results in a growth rate of approximately 6.5 percent.

The remarkable rise in cargo along the Europe-Asia route in 1968 and 1969 reflects a surge in shipments of coal and iron ore to Japan.

Although canal traffic to Japan and the other Far East destinations has grown relatively and absolutely, this has been accompanied by growth involving other regions and trade routes. For example, the sharply rising traffic along the South American Intercoastal Route reflects a considerable increase in petroleum movements from Venezuela to West Coast South American ports. Cargo shipments from the West Indies to the West Coast United States have increased significantly. For most of the period, the East Coast South America – West Coast United States route showed gains but has declined in the last few years because of a considerable drop in cargoes originating in West Coast United States ports. A significant increase in Europe-Oceania trade between 1967 and 1968 is attributed in part to closure of the Suez Canal. Except for a decline in traffic in FY 1968, the East Coast USA – Oceania route has shown a healthy growth trend. United States Intercoastal, East Coast United States – West Coast South America and Europe – West Coast South

TABLE IV-9

MAJOR TRADE ROUTES
PANAMA CANAL COMMERCIAL OCEAN TRAFFIC
SELECTED FISCAL YEAR 1947 - 1969
(000 Long Tons of Cargo)

Trade Route	1947	1950	1955	1960	1965	1966	1967	1968	1969
East Coast USA - Japan	532	2,079	5,450	10,719	17,457	20,396	24,145	29,089	32,918
East Coast USA - Asia (less Japan)	2,182	2,130	2,870	3,341	5,083	5,507	6,133	6,920	7,863
Europe - West Coast USA/[1] Canada	4,619	2,828	5,125	6,792	6,921	7,374	6,907	7,483	7,605
East Coast USA - West Coast South America	3,475	4,615	5,970	10,147	7,824	7,629	7,809	6,677	7,334
Europe - West Coast South America	1,314	1,545	2,527	4,584	7,153	6,645	5,694	5,740	5,570
South American Intercoastal	74	116	518	1,115	1,983	2,798	3,248	3,650	3,971
USA Intercoastal[1]	3,401	8,315	6,833	7,364	5,823	5,787	5,153	4,713	3,851
Europe - Asia	20	71	74	245	215	251	676	4,118	3,185
West Indies - West Coast USA[1]	247	349	964	797	2,055	2,145	2,866	2,968	2,883
West Indies - Asia	47	85	463	696	1,586	1,848	2,190	2,854	2,795
Europe - Oceania	1,148	1,718	2,329	2,082	2,379	2,255	2,085	2,682	2,635
East Coast South America - West Coast USA[1]	257	210	431	2,624	2,982	2,958	2,653	2,340	2,502
East Coast USA - Oceania	885	780	1,014	1,057	2,435	2,938	3,004	2,404	2,415
All Other routes	3,470	4,031	6,078	7,695	12,677	13,173	13,630	14,912	15,864
TOTAL	21,671	28,872	40,646	59,258	76,573	81,704	86,193	96,550	101,391

[1] Includes Alaska and Hawaii

SOURCE: Panama Canal Company Annual Reports

America show declining trends for the period. Detailed data on origins and destinations of Commercial Ocean Traffic along all trade routes during the period Fiscal Years 1947 through 1969 are contained in Appendix 2, Analysis of Panama Canal Cargo Tonnage History.

As stated previously, the dynamic growth of Panama Canal traffic since World War II can be attributed primarily to the continued emergence and rapid growth of new traffic patterns. Certain spectacular events have acted as catalysts, however, in causing rapid increases in canal traffic at certain times. In the decade 1950-1960 the Korean conflict, the closure of the Suez Canal, and initiation of Japanese economic expansion fall in this category. The decade was also characterized by a steadily rising volume of U.S. cargo, an unusual increase in cargo movements to Europe, and an extraordinary increase in the numbers and sizes of all classes of ships. In the decade 1960-1970 the continuation of Japanese economic expansion, hostilities in Southeast Asia, and the second closure of the Suez Canal are the most important single events contributing to the dramatic rise in canal traffic.

Table IV-10 further illustrates the impact that Japanese economic expansion has had on canal traffic since World War II. It provides a comparison of commercial cargo tonnage shipments to Japan and other Asiatic designations with commercial shipments to all other destinations. It shows that trade to the Far East, with particular emphasis on that destined for Japan, has been growing at an extraordinary rate in the last two decades as compared to traffic moving to non-Asiatic destinations. In 1969 cargo tonnage shipments to Asia amounted to 38.8 percent of cargo tonnage moving to all destinations, with Japan alone representing 33 per cent of the total. Of all commercial cargo tonnage shipped from the Atlantic to the Pacific in 1969 (not shown in Table IV-10), Asia represented 60.9 per cent of Pacific-bound cargo and Japan alone 51.8 per cent. Table IV-11 portrays cargo movements to and from Japan as well as cargo tonnage traffic involving all other Asiatic origins and destinations. The last column on Table IV-11 lists all other commercial cargo tonnage moving through the Panama Canal. In 1969 shipments to and from Asia constituted approximately 50 per cent of all commercial cargo tonnage shipped through the canal, while shipments to and from Japan comprised 40.4 per cent of the total.

Effect of Military Operations on Panama Canal Traffic

Table IV-12 illustrates the effect o[illegible]ilitary operations in Southeast Asia on Panama Canal traffic. It provides an overall [illegible]ry of Panama Canal traffic for Fiscal Years 1964-1969, spanning the years of inc[illegible]sing Military Assistance Program support and initiation and continuation of major hostilities. Vietnam has affected traffic directly and indirectly. The direct impact is immediately noticeable in the sharp rise in U.S. Government traffic which, pre-Vietnam, averaged something less than 300 transits and 1.4 million tons of cargo annually. While sharply rising Government traffic directly reflects the heightened level of involvement in Vietnam, increased ocean-going commercial traffic is also indirectly a result of it. Offshore purchases by the Department of Defense, military personnel and U.S. industrial spending in the Pacific basin have tended to stimulate the economies of a number of countries that are important to the canal, principally Japan. In 1969, for the first time since the initiation of large-scale hostilities, U.S. Government traffic showed an absolute decline in transits and cargo tonnage. This reflects the decision of November 1, 1968 to halt bombing targets in North Vietnam.

TABLE IV-10

COMPARISON OF COMMERCIAL CARGO SHIPMENTS TO ASIA WITH OTHER PANAMA CANAL TRAFFIC FISCAL YEARS 1947 THROUGH 1969

(Cargo Long Tons x 10^6)

			Destination of Commercial Cargo			
Fiscal Year	Total P.C. Cargo	Commercial Cargo	Japan[1]	Other[2] Asia	Total Asia	Total Non-Asia
1947	22.7	21.7	0.5	1.8	2.3	19.4
1948	25.7	24.1	1.1	1.3	2.4	21.7
1949	27.8	25.3	2.2	1.0	3.2	22.1
1950	30.4	28.9	2.0	0.9	2.9	26.0
1951	31.3	30.1	2.7	0.7	3.4	26.7
1952	36.9	33.6			5.1	28.5
1953	41.2	36.1			6.6	29.5
1954	41.9	39.1			7.8	31.3
1955	41.5	40.6			7.1	33.5
1956	46.3	45.1	6.3	2.0	8.3	36.8
1957	50.7	49.7	9.4	3.0	12.4	37.3
1958	49.0	48.1	7.8	1.9	9.7	38.4
1959	52.3	51.2	8.0	1.6	9.6	41.6
1960	60.4	59.3	11.0	2.0	13.0	46.3
1961	65.2	63.7	14.2	2.5	16.7	47.0
1962	69.1	67.5	16.5	3.9	20.4	47.1
1963	63.9	62.2	13.7	2.6	16.3	45.9
1964	72.2	70.6	17.8	3.2	21.0	49.6
1965	78.9	76.6	17.9	3.4	21.3	55.3
1966	85.3	81.7	19.6	3.6	23.2	58.5
1967	93.0	86.2	24.1	4.7	28.8	57.4
1968	105.5	96.5	32.2	5.2	37.4	59.1
1969	108.8	101.4	33.5	5.9	39.4	62.0

Notes: 1. Specific data on shipments to Japan not available for Fiscal Year 1952-Fiscal Year 1955, incl.

2. Includes British East Indies, China, Formosa, Hong Kong, Indonesia, North Korea, Philippine Islands, Russia, South Korea, South Vietnam, Thailand, and other unspecified destinations. Does not include Pacific-Atlantic shipments to the Middle East, which are included in the "Total Non-Asia" column.

SOURCE: Panama Canal Company Annual Reports

TABLE IV-11

COMPARISON OF COMMERCIAL CARGO SHIPMENTS TO AND FROM ASIA WITH OTHER PANAMA CANAL TRAFFIC FISCAL YEARS 1947 THROUGH 1969

(Cargo Long Tons x 10^6)

Fiscal Year	Total P.C. Cargo	Commercial Cargo	To & From[1] Japan	To & From[2] Other Asia	To & From All Asia	To & From Non-Asia
1947	22.7	21.7	0.6	2.2	2.8	18.9
1948	25.7	24.1	1.1	2.1	3.2	20.9
1949	27.8	25.3	2.4	2.6	5.0	20.3
1950	30.4	2[illegible].9	2.2	2.2	4.4	24.5
1951	31.3	30.1	3.0	2.4	5.4	24.7
1952	36.9	33.6			6.9	26.7
1953	41.2	36.1			8.8	27.3
1954	41.9	39.1			10.0	29.1
1955	41.5	40.6			9.4	31.2
1956	46.3	45.1	7.2	3.9	11.1	34.0
1957	50.7	49.7	10.2	4.8	15.0	34.7
1958	49.0	48.1	8.5	3.3	11.8	36.3
1959	52.3	51.2	9.1	3.2	12.3	38.9
1960	60.4	59.3	12.2	3.7	15.9	43.4
1961	65.2	63.7	15.3	4.5	19.8	43.9
1962	69.1	67.5	17.8	6.1	23.9	43.6
1963	63.9	62.2	15.4	4.7	20.1	42.1
1964	72.2	70.6	19.8	5.4	25.2	45.4
1965	78.9	76.6	21.4	5.7	27.1	49.5
1966	85.3	81.7	24.5	6.4	30.9	50.8
1967	93.0	86.2	28.9	7.4	36.3	49.9
1968	105.5	96.5	38.1	8.3	46.4	50.1
1969	108.8	101.4	41.0	9.5	50.5	50.9

NOTES: 1. Specific data on shipments to and from Japan not available for Fiscal Year 1952-Fiscal Year 1955, incl.

2. Includes British East Indies, China, Formosa, Hong Kong, Indonesia, North Korea, Philippine Islands, Russia, South Korea, South Vietnam, Thailand, and other unspecified Asiatic origins and destinations. Does not include origins and destinations in the Middle East, which are included in the "To & From Non-Asia" column.

SOURCE: Panama Canal Company Annual Reports

TABLE IV-12

EFFECT OF MILITARY OPERATIONS IN SOUTHEAST ASIA ON TRAFFIC THROUGH PANAMA CANAL – FISCAL YEARS 1964 THROUGH 1969

Fiscal Year	Total* Transits	Commercial Ocean Transits	U.S. Govt. Ocean Transits	Total* Cargo Tonnage (Long Tons)	Commercial Ocean Cargo Tonnage (Long Tons)	U.S. Govt. Ocean Cargo Tonnage (Long Tons)
1964	12,945	11,808	285	72,168,690	70,550,090	1,777,269
1965	12,918	11,834	284	78,922,931	76,573,071	1,923,538
1966	13,304	11,925	591	85,323,463	81,703,514	3,220,190
1967	14,070	12,412	879	92,997,958	86,193,430	6,147,479
1968	15,511	13,199	1,504	105,538,318	96,550,165	8,497,221
1969	15,327	13,150	1,376	108,793,069	101,391,132	7,210,063

*Includes all other types of traffic, i.e., Free Ocean Traffic, Small Commercial Traffic, Small U.S. Government Traffic, and Small Free Traffic.

SOURCE: Panama Canal Company Annual Reports

If peace negotiations lead to a termination of hostilities in Southeast Asia, the immediate effect will be a lowering in demand for canal services generated by the conflict. However, this is expected to have only a short-term effect on canal traffic growth. In this connection, a brief examination of traffic experience during and after the Korean conflict is in order. Table IV-13 contains traffic data spanning the period of conflict and the post-war years. The major impact of the war is illustrated in the sharp rise in U.S. Government ocean traffic (reaching a peak in Fiscal Year 1953) and then dropping off to normal experience for this category of traffic in Fiscal Years 1955 and 1956. The overall effect of the cessation of hostilities appears to have created a plateau of growth of total cargo tonnages from the end of Fiscal Year 1953 through 1955, due to an absolute decrease in U.S. Government traffic but a continuing growth in commercial ocean traffic. This effect was only temporary, however; commercial cargo tonnage continued to grow and, in fact, made a great surge in Fiscal Year 1956. The post-war situation in Vietnam could be similar.

Conclusion

In conclusion, the growth in Panama Canal traffic since World War II has resulted only in part from orderly growth trends in individual components of traffic. It has been, to a considerable extent, a growth brought about by surges in traffic, followed by periods of consolidation of gains and accompanied by a marked increase in the size of ships. Current trends portend continued growth in most aspects of canal traffic.

Views of Ship Operators and Oil Companies

As part of the examination of economic factors bearing on the feasibility of a sea-level canal, the Commission and Study Group conducted a comprehensive survey of the views and plans of shipping interests and oil companies as they relate to possible future use of an interoceanic canal in the American Isthmus. The results of the survey were very inconclusive. Most commercial interests base their planning on short and midrange forecasts of future trends. In a highly volatile operation such as that engaged in by the petroleum industry it is most difficult, if not impossible, to predict the long-range future.

Approximately 25 major U.S. shipping companies participated in the survey. About one-half declined to make any definitive response on projected use of a sea-level canal (if constructed and of adequate size) through the year 2000. Four companies indicated a regular need for transiting cargoes, primarily of a dry bulk nature, in vessels of the 100,000 DWT type. Two foresaw a need for vessels of the 200,000 DWT type. Most of the shipping companies surveyed indicated that a moderate increase in tolls for future sea-level canal traffic would be acceptable. A substantial increase (e.g., 50 per cent) would result in serious consideration of alternate routes.

Twenty major oil companies were queried on the need for constructing a sea-level canal which would accommodate 250,000 DWT tankers. Of the 15 companies that provided a response, 4 favored construction, 7 felt that the canal could not be justified on the basis of projected petroleum movements, 3 had no opinion, while 1 foresaw the desirability of moving large combination bulk/oil carriers through the canal. Some of the companies pointed out the possibility of the economic attractiveness of a transisthmian pipeline (in which the Government of Panama is interested) vis a vis a canal, unless the canal tolls rates were competitive in nature. The companies interested in the recent oil developments on

TABLE IV-13

EFFECT OF MILITARY OPERATIONS IN KOREA ON
TRAFFIC THROUGH PANAMA CANAL – FISCAL YEARS 1950 THROUGH 1956

Fiscal Year	Total* Transits	Commercial Ocean Transits	U.S. Govt. Ocean Transits	Total* Cargo Tonnage (Long Tons)	Commercial Ocean Cargo Tonnage (Long Tons)	U.S. Govt. Ocean Cargo Tonnage (Long Tons)
1950	7,694	5,448	443	30,364,982	28,872,293	1,429,283
1951	7,751	5,593	693	31,281,525	30,073,022	1,165,986
1952	9,169	6,524	774	36,902,903	33,610,509	3,237,311
1953	10,210	7,410	1,064	41,203,401	36,095,349	5,049,922
1954	10,218	7,784	800	41,882,368	39,095,067	2,708,380
1955	9,811	7,997	296	41,548,037	40,646,301	838,305
1956	9,744	8,209	266	46,331,901	45,119,042	1,150,121

*Includes all other types of traffic, i.e., Free Ocean Traffic, Small Commercial Traffic, Small U.S. Government Traffic, and Small Free Traffic.

SOURCE: Panama Canal Company Annual Reports

Alaska's North Slope and in Colombia Ecuador recognized the possible impact on traditional oil transportation and distribu patterns. However, it is too early to reach conclusions on the impact of these developments on interoceanic canal petroleum movements.

Technological Developments

Growth in world trade will require a parallel growth in total world shipping capacity. While air freight is expected to increase its potential share of high-valued and other non-bulk cargoes in oceanborne trade, by far the largest part of transoceanic trade will move in ships. Expected improvements in shipping efficiency will enable a better ratio of cargo moved per ton of capacity, but the required world shipping capacity will increase considerably. Bulk carriers will continue to grow in size but this growth will be subject to several constraints, including port size and depth, ship handling and cargo transfer facilities. Most non-bulk commodities will move in unitized loads.

The principal alternatives to ocean transport for products currently moving through the Panama Canal (other than ocean movement via The Cape of Good Hope or the Straits of Magellan) are:

(1) Air movement.

(2) Rail movement between Pacific ports and Gulf or Atlantic ports combined with ship movements on each coast (the landbridge concept.)

(3) Pipeline movement between the oceans or inland from coastal ports.

It is not possible to make a reliable long-term prediction of costs of these alternatives relative to the costs of surface shipping via an Isthmian canal. However, the current state of the art of technological forecasting suggests that cost reductions in the modes which compete with oceanborne traffic will have only marginal effect on the total of potential future canal tonnages. High value-to-weight-ratio products already move long distances most economically by air. Larger and more efficient aircraft will continue to lower air freight costs, and in the future a very large portion of manufactured products will move by air rather than by surface transport. However, the efficiencies of ship movements of raw materials, agricultural products, heavy manufactured goods and containerized goods are also increasing. Aircraft are not expected to be able to compete for most cargoes of this nature during the remainder of this century. Movements by air will grow considerably but tonnages moving by surface transport will continue to increase relatively unaffected by this trend.

The potential competition of rail transport between the oceans has existed throughout the life of the present canal. The containership/landbridge concept is evolutionary rather than revolutionary, and it is expected to have little ultimate effect on the growth of tonnages through the Panama Canal. Only high value cargoes suitable for containerization could move more economically by the landbridge, and its potential competitive position would be vulnerable to increases in rail and port charges and decreases in ocean freight rates.

The potential for pipeline competition to the Panama Canal is not new. It has existed throughout the growth of petroleum movements through the canal. In the future, pipelines are expected to attract many new petroleum movements that would otherwise move through an Isthmian canal in tankers. Although petroleum movements currently represent a significant share of canal traffic, the tonnages involved are a very small portion of world petroleum movements. The discovery of the new petroleum sources in Alaska and the

western part of South America is not expected to cause drastic changes in the proportion of petroleum tonnages in the totals that will move through an Isthmian canal in the future. The petroleum industry is considering the merits of a transisthmian pipeline, and pipelines from Alaska to the U.S. Far West and from the Pacific Coast to the U.S. Midwest, as well as use of the Northwest Passage, are also under consideration.

Potential Cargo Tonnage Forecasts

The Shipping Study Group considered several alternative assumptions and methods for forecasting future potential cargo tonnage, ultimately selecting the potential tonnage forecast relating canal traffic to regional economic development and described in detail in Appendix 3, Isthmian Canal Potential Tonnage Forecast, as the basic forecast for interoceanic canal capacity and revenue planning purposes. However, a lower tonnage forecast was developed under different assumptions and is presented for alternative revenue planning purposes to demonstrate the magnitude of possible financial risk. Two other projections which are considered are of use in that they further delineate the range of possibilities which conceivably can be considered and also serve as points of comparison for the potential tonnage forecast and low tonnage forecast. The other projections are termed the high projection and the 54-year trend projection and are recorded with the potential tonnage and low tonnage forecasts in Table IV-14 and Figure IV-3.

High Projection

Panama Canal tonnage has grown exponentially at an average annual rate of approximately 6.5% during the period 1947-1969. Projecting this exponential rate of

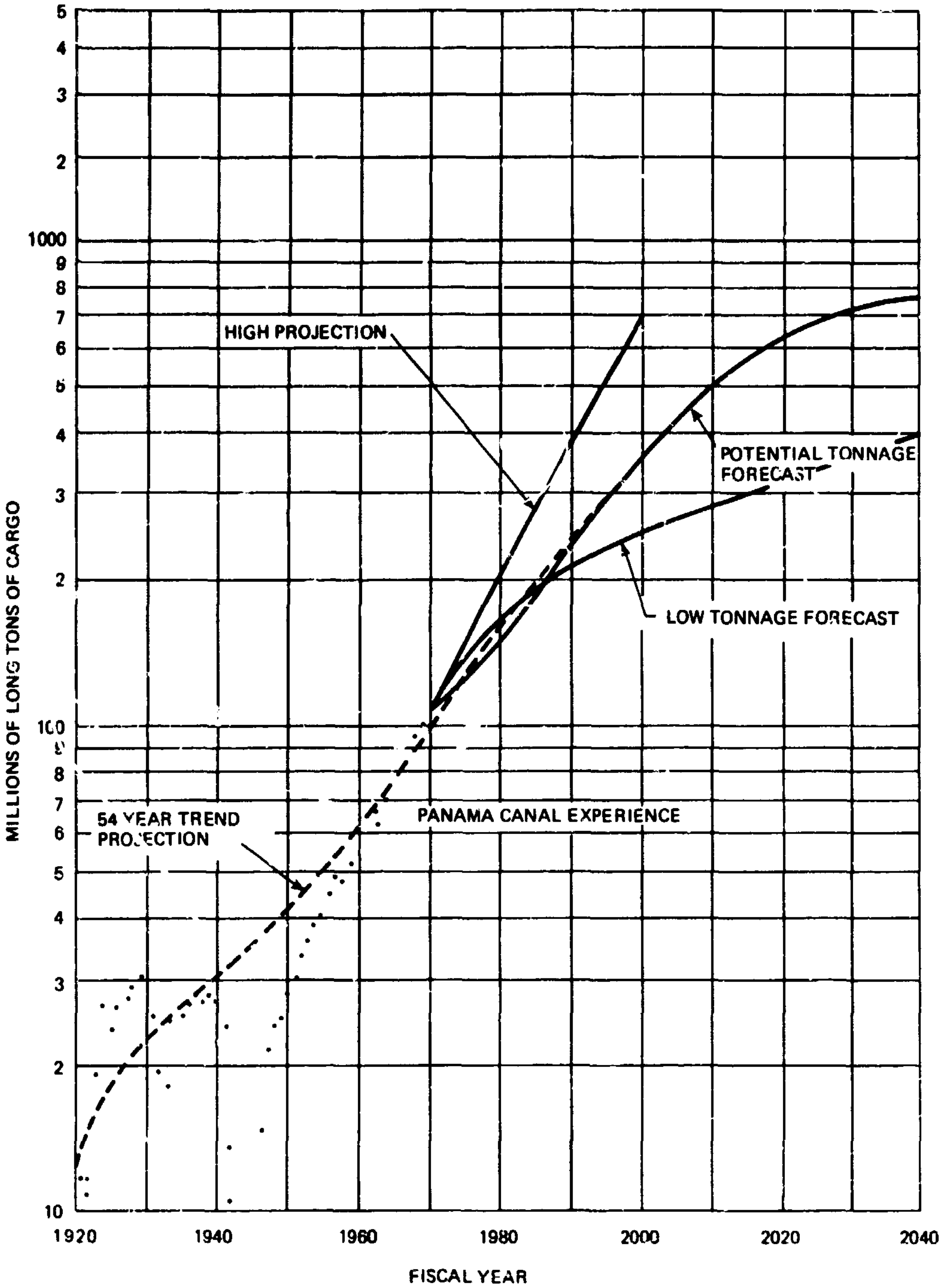
TABLE IV-14

FORECAST OF TOTAL POTENTIAL CARGO TONNAGE FOR A TRANSISTHMIAN CANAL

(Millions of Long Tons of Cargo)

	1970	1980	1990	2000	2010	2020	2030	2040
High Projection	111	208	391	734	–	–	–	–
Fifty-Four Year Trend Projection	101	160	246	366	–	–	–	–
Potential Tonnage Forecast	111*	157	239	357	503	643	743	778
Low Tonnage Forecast	111	171	218	254	290	325	363	403

*Note: The potential tonnage forecast is based on analysis of 1950-1967 data and is projected forward from a best fit curve which does not necessarily intersect any or all points established by actual returns. The 1970 forecast was actually 97,196,000 long tons of commercial ocean cargo plus 2,000,000 tons for government cargo. For 1970, the figure of 111,000,000 long tons of cargo for total potential cargo tonnage is used as a most probable value for that year.



POTENTIAL CARGO TONNAGE
ISTHMIAN CANAL

FIGURE IV-3

growth from a 1970 base of 111 million long tons produces a potential tonnage of 734 million long tons in the year 2000. Such a high growth rate assumes a constant relationship of world economic growth to trade and a continuation of world economic growth at the high rates of 1947-1969. World economic growth is expected to continue to increase 4.4% annually to year 2000, and U.S. economic growth to equal about the same for this period. This economic growth will result in even greater growth in world oceanborne trade. The Study Group considers the projection of cargo seven-fold by the year 2000 to be extremely optimistic. The catalytic influence of unique economic conditions prevailing after World Was II (particularly in Japan) that spurred the growth of Panama Canal traffic during this period is not expected to continue indefinitely. As this projection is extended to the year 2040, it results in a cargo tonnage estimate of 9 billion long tons. While such a projection may fall within the realm of possibility, it is most unlikely that any such astronomical cargo tonnage would ever materialize. Continued growth at the overall exponential rate experienced over the past two decades would imply continuation of the historical pattern of Japan trade and, parenthetically, would result in totals which would require several new canals to accommodate.

Fifty-Four Year Trend Projection

This projection is based on a regression analysis of the commercial ocean tonnage experience of the Panama Canal extending back to 1915. The tonnage points were tested by the method of least squares for a curve giving the best fit through the computer program for curve fitting developed by the Maritime Administration. Curves tested were linear, parabolic, hyperbolic, second order polynomial, third order polynomial, and exponential. It was found that the curve giving the best fit is a third order polynomial as recorded in Table IV-14 and Figure IV-3. As a completely independent projection of the totally aggregative type, its very close agreement with the potential tonnage forecast through the year 2000 reinforces the credence which can be given to the basic forecast.

Potential Tonnage Forecast

The potential tonnage forecast is based on an examination of the historical relationship between time series growth of commercial cargo tonnage passing through the Panama Canal and the Gross Product growth of the geographic regions that contributed to this traffic. This aggregative type of approach, modified to the extent that specific regional components of the world are evaluated rather than total aggregation at the world level, is a logical and statistically reliable means of making the very long range forecast required by this study. Aggregation at the world level would omit important developments in regional economic evolution. On the other hand, further decentralization of the aggregative approach to the national level would yield time series data characterized by perturbations unsuitable to the statistical regression analysis employed in the forecast methodology. Straight-line projections of historical cargo tonnage growth, predicted on gross assumptions concerning future growth, were considered to be inadequate even though results might approximate the regional approach. A disaggregative approach, based on analysis of resource development, markets, commodity movements involved in distribution patterns, and other specific economic factors, was considered to be impractical for reasons that have already been stressed in foregoing portions of this study. The possibility of combining a disaggregative

approach involving detailed commodity analysis of specified regions along with an aggregative approach with respect to the remainder of the regions was considered and rejected. It was felt that this would unduly warp the total forecast by overemphasizing the more predictable events that might be associated with the regions subjected to such an analysis at the expense of the unpredictable events associated with the other regions.

The method employed to manipulate the data pertinent to the potential tonnage forecast is the normal one employed in the aggregative technique, i.e., statistical regression analysis. This measures the change in one or more variables involved in the dynamics of the aggregation against the change in others to test the degree of correlation; the statistical validity is measured by the correlation coefficient.

Fifteen geographic regions were identified, aggregating the total of nations that have produced all Panama Canal commercial ocean tonnage. These regions are shown as follows in order of importance with respect to volume of cargo by origin in Fiscal Year 1969: East Coast United States, West Coast South America, East Coast South America, Japan, West Indies, Europe, West Coast Canada, West Coast United States, Asia (less Japan), Oceania, West Coast Central America/Mexico, East Coast Central America/Mexico, East Coast Canada, Africa, and Asia (Middle East). Time series data for the period 1950 through 1967 were developed for each region consisting of the regional product, the per capita product and tonnage exports through the canal. The data were manipulated in various ways to obtain an acceptable degree of correlation for forecast purposes. The approach which produced a high degree of correlation was that which related the gross product of each region (the independent variable) to the cargo originating from that region for export through the Panama Canal to a regional destination (the dependent variable). Thirteen of the 15 regional models had correlation coefficients over .8; only one model (West Coast United States) was inadequate. The observation of such a preponderance of valid statistical relationships derived from a single independent variable is significant. The West Coast United States model's correlation coefficient could undoubtedly be improved by increasing the complexity of the equation, but such an approach would conflict with the logic of the forecast and would increase the likelihood of error in estimating the growth of the independent variables.

Japan required special consideration because its phenomenal economic growth subsequent to World War II has had a disproportionate effect upon the growth of Panama Canal traffic. This dominant influence has been discussed in some detail in the Economic Considerations section of Chapter IV. Table IV-15 further illustrates its impact on the aggregate of all commercial shipments through the canal in the past two decades. The table shows that shipments of commercial cargo to Japan increased from approximately 2 million long tons in 1950 to 33.5 million tons in 1969, of which approximately four-fifths originated on the East Coast of the United States. The table also indicates that shipments of commercial cargo from Japan increased from a little more than 200,000 long tons in 1950 to 7.4 million tons in 1969, of which approximately three-fourths was enroute to the East Coast of the United States.

This rapid growth in canal cargo shipments to Japan during the past ten years, from 8 million tons in 1959 to 33.5 million tons in 1969, has been coincident with and was caused primarily by the tremendous expansion of the Japanese steel industry, which depends upon imports of raw material, particularly coking coal, iron ore, and scrap metal. Approximately

TABLE IV-15

ROLE OF JAPAN IN PANAMA CANAL TRAFFIC FISCAL YEARS 1950 THROUGH 1969

(Millions of Long Tons of Cargo)

Fiscal Year	Total Commercial Ocean Traffic	To* Japan	From* Japan	Total Non-Japan
1950	28.87	1.99	.22	26.66
1951	30.07	2.69	.33	27.05
1952	33.61			
1953	36.10			
1954	39.10			
1955	40.65			
1956	45.12	6.34	.88	37.90
1957	49.70	9.38	.82	39.50
1958	48.12	7.83	.67	39.62
1959	51.15	7.97	1.11	42.07
1960	59.26	10.99	1.22	47.05
1961	63.67	14.20	1.13	48.34
1962	67.52	16.50	1.25	49.77
1963	62.25	13.70	1.75	46.80
1964	70.55	17.78	2.03	50.74
1965	76.57	17.91	3.45	55.21
1966	81.70	19.59	4.87	57.24
1967	86.19	24.09	4.77	57.33
1968	96.55	32.16	5.96	58.43
1969	101.39	33.56	7.40	60.43

*Specific data on shipments to and from Japan not available for Fiscal Years 1952-1955, incl.

SOURCE: Panama Canal Company Annual Reports

15.7 million tons of coal were shipped through the Panama Canal to Asia in 1969, with the vast bulk of this commodity moving from the East Coast United States to Japan. Other important commodity movements to Japan tonnage-wise include grains of various types, scrap metal, and phosphate rock. In more recent years the surge in shipments from Japan has consisted primarily of manufacturers of iron and steel destined for the East Coast United States.

The main thrust of Japanese economic progress during the past decade or so has been achieved through intensive domestic investment (particularly in plant and equipment) to exploit a rapidly expanding domestic market created through increases in real income and low rate of population growth. Although the pattern is expected to continue for the short range, eventual diminution in the surplus rural labor supply is expected to cause inflationary

pressures. Additionally, the long-range prospects for real product growth must consider the critical limitation of land. The historic advantages of technological advance will probably not continue to propel the Japanese economic development along past lines of growth. It was decided, therefore, to assume a gradually declining product growth rate for Japan to 5% by the year 2000 which is reflective of such aforementioned institutional and economic constraints expressed in performance levels exhibited by other mature island nations such as Great Britain. This resulted in a lower figure of cargo tonnage generation from Japan.

Trade between Japan and the United States will continue to exert a dominant influence on oceanborne trade and interoceanic canal traffic. The two nations are each the largest overseas trading partner of the other but the balance of trade has shifted progressively and dramatically in Japan's favor. The United States had a trade surplus with Japan throughout the post-war period through 1964. In 1965, the United States had a $376 million deficit which expanded in 1969 to $1.4 billion. This trend will continue for the foreseeable future.

The factors leading to this reversal are complex but are related basically to Japanese investment in key export industries, rapidly rising Japanese industrial productivity, and concentration upon the United States as the major export market. At the same time, the continued high rate of United States economic growth has stimulated imports and domestic inflation has contributed to the steadily deteriorating ability of the United States to compete in the world and Japanese markets.

The United States is by far Japan's largest trading partner and furnishes historically about 25% (1969: $3.5 billion) of Japan's total import requirements. U.S. exports to Japan follow a consistent pattern composed primarily of agricultural commodities, machinery and transport equipment, chemicals and fuels. Certain regions of the United States, such as the wheat producing areas of the Mid-West, rely heavily on exports to Japan. Although the pattern of U.S. exports to Japan has been generally constant, important changes have taken place in its composition. U.S. agricultural exports continue to loom large, for example, but the products have changed. Our exports of raw cotton have declined in recent years, but have been more than compensated by shipments of soybeans, feed grains and logs.

Although the two-way trade has continued to expand rapidly since 1964, Japan's exports to the United States have increased at a more rapid rate and reached $4.9 billion in 1969. Japan's shipments to the United States consist primarily of finished goods, which have shown a steadily growing diversity and a marked change in emphasis. Many of the more traditional exports have declined and been replaced by iron and steel, automobiles and electronic items. Further expansion in United States-Japan trade can be expected as U.S. producers attempt to meet the needs of Japan's expanding industrial and mass-consumption society and Japan's export industries, geared to the U.S. market, seek to utilize and expand opportunities.

There are no current indications of diminishing growth of canal traffic to and from Japan. In this connection, Australian Government officials predict that Japan's steel production and requirements for coal imports will continue to surge – at least for the near range, and that Australia's share of the Japanese coal import market will not impact against the U.S. portion of the market. If this trend continues over the long range, and other possible constraints on U.S. coal exports to Japan do not materialize, it will lend substantive support to the potential cargo tonnage forecast – at least in an implied way as concerns the aggregate forecast of tonnage from the U.S. East Coast (coal shipments to Japan being the

most significant commodity tonnage-wise). Even if Japan's dependence on U.S. raw materials (cooking coal and metal scrap) for expanding industrialization should diminish in the future, there are other significant bulk commodities such as grains and phosphate rock that have a potential for increasing volumes of shipments through a canal to Japan.

Using the correlations and forecasts of world and regional product available from U.S. Government and United Nations sources, forecasts of commercial traffic available to a transisthmian canal were made. The "best fit" curve analysis of the 1950-1967 data projected by the foregoing method resulted in a forecast of 355 million tons of potential commercial canal traffic for the year 2000. The detailed forecast is shown in Table IV-16. Total yearly traffic was obtained by adding 2 million long tons to the commercial traffic to account for a peacetime level of U.S. Government use.

It is emphasized that a wide range of variations within some of the 15 regional projections could be statistically and judgmentally supported. For example, the statistically derived forecast of 58.6 million tons of cargo originating in West Coast South America (Table A3-60), West Coast South America, Curve: 3) could be optimistic, especially if recent discoveries of oil in Colombia and Equador do not result in significant oil shipments through an interoceanic canal to the Atlantic Basin. On the other hand, the forecast of 3.5 million tons of cargo originating in West Coast USA (Table A3-56, West Coast USA, Curve: 3) in year 2000 could be pessimistic in view of the possibility that the recent discoveries of large oil deposits on Alaska's North Slope could result in major oil shipments through a canal on a random basis. Therefore, the forecast pertaining to each regional component is not presented as being categorically precise. However, each is presented as sufficiently sound in concept that variations are just as likely to be above the projection as below it; hence, the total of the forecast for the fifteen regions out to the year 2000 has as high a degree of reliability as can be given any such long-range forecast.

From the year 2000 to 2040, a curve of uniformly declining rate (or slope) was constructed such that at year 2040 the rate of increase is zero. The commercial ocean tonnage derived for year 2040 is 776 million tons to which two million tons are added for non-commercial cargo to give 778 million tons as the total tonnage. The "bending down" of the rate of growth in this period resulted basically from inability to forecast world trends from 30 to 70 years into the future. Many aspects of world development could have a profound effect upon oceanborne trade. Populations, availability of natural resources, industrial and agricultural development, technological innovations – all could have effects which would maintain or diminish the rate of growth of potential canal tonnage existing at year 2000. The results of alternative assumptions of uniformly declining rates of growth between years 2000 and 2040 are shown in Figure IV-4. The mean curve diminishing to zero percent rate of growth at 2040 was selected as a conservative growth estimate for the period 2000 to 2040. The potential tonnage which would pass through an interoceanic canal at year 2040 is thus forecast to be about seven times that presently passing through the Panama Canal.

A considerably lower forecast would not allow for the possibility of significant unusual growth of commodity movements to and from regions other than Japan in an expanding world economy. However, it should be pointed out that foreign markets now closed to United States trade, such as Communist China, North Korea, North Vietnam, and Cuba, could exert a positive influence on the growth of interoceanic canal traffic in the future.

TABLE IV-16

POTENTIAL CARGO TONNAGE FORECAST[1]
(Millions of Long Tons of Cargo)

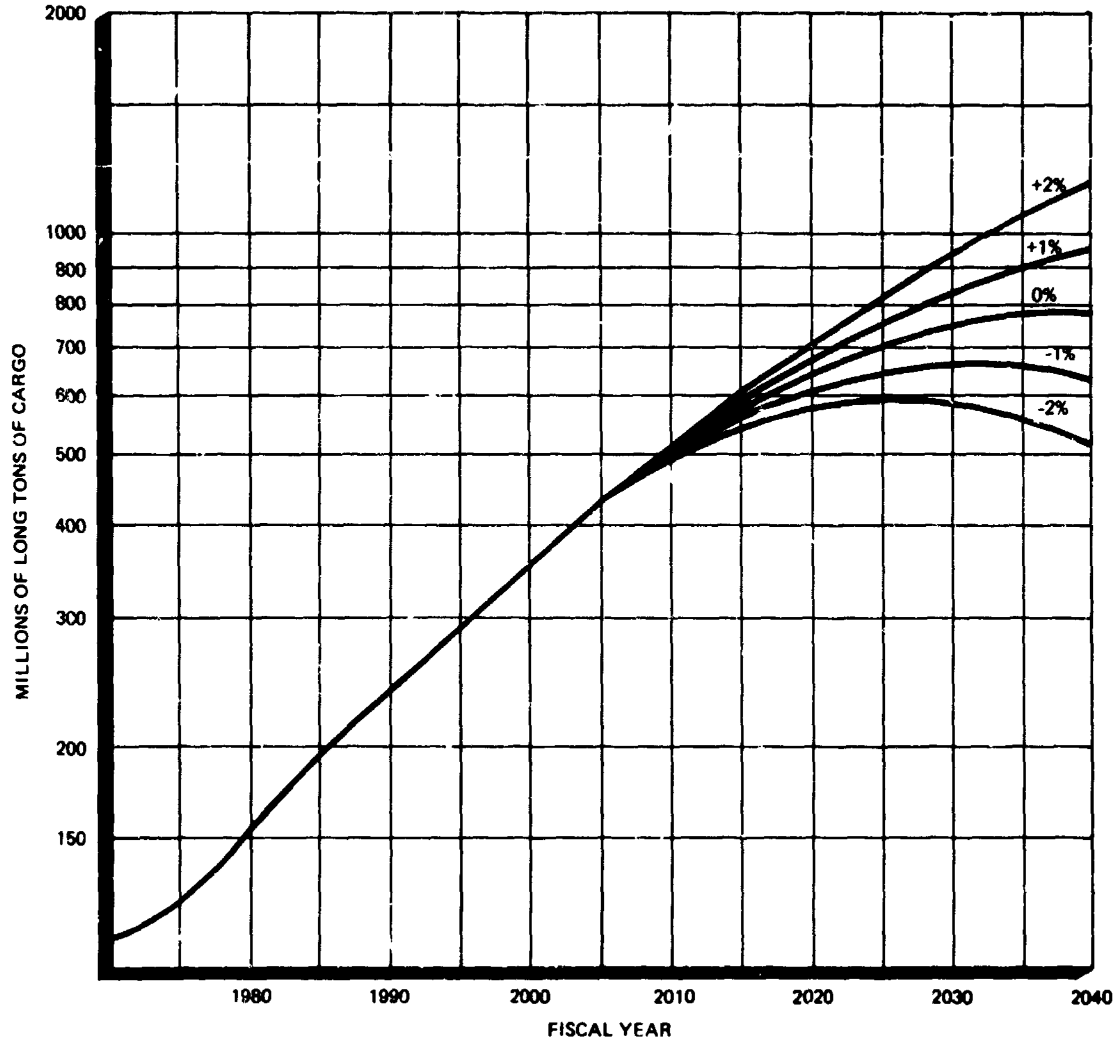
Region of Origin	1970[2]	1980	1990	2000
Atlantic Basin				
East Coast USA	32.5	53.5	82.3	122.1
East Coast Canada	1.2	2.0	3.3	5.2
East Coast Central America/ Mexico	1.0	2.1	4.2	7.8
East Coast South America	10.1	15.6	21.1	26.6
West Indies	6.7	9.3	11.9	14.5
Europe	4.6	6.8	10.4	16.0
Asia (Middle East)	–	0.1	0.1	0.3
Africa	0.3	0.6	1.0	1.5
TOTALS	56.4	90.0	134.3	194.0
Pacific Basin				
West Coast USA	6.1	5.6	4.8	3.5
West Coast Canada	5.8	8.3	12.0	17.8
West Coast Central America/ Mexico	1.9	3.5	6.5	11.7
West Coast South America	15.4	24.1	37.6	58.6
Oceania	2.9	4.3	6.4	9.6
Japan	5.8	14.4	28.8	50.0
Asia (less Japan)	2.9	4.3	6.6	10.2
TOTALS	40.8	64.5	102.7	161.4
GRAND TOTALS	97.2[2]	154.5	237.0	355.4

NOTES: [1]Tonnages shown are for commercial cargo. For total cargo add 2 million tons to the Grand Totals for each forecast year.

[2]See note for Table IV-14.

Other markets in the Pacific Basin, such as Taiwan and Southeast Asia, have potential for exponential growth of canal traffic. The Australians mention interesting possibilities of future interoceanic canal shipments of coal and iron ore to Europe. Again, it is axiomatic in a long-range forecast of this nature that predictable events normally have a downward bias while the unpredictable events and forces and trends result in substantial increases in economic growth and world trade.

Further details of the forecast are contained in Appendix 3, Isthmian Canal Potential Tonnage Forecast.



POTENTIAL CARGO TONNAGE ISTHMIAN CANAL
ALTERNATE RATES OF GROWTH FOR YEARS 2000 - 2040

FIGURE IV-4

Low Tonnage Forecast

The low tonnage forecast of approximately 250 million tons of commercial ocean cargo by the year 2000 is based on separate forecasts of Japan trade and all other commercial cargo. The rationale for the forecast is derived from an analysis of Panama Canal cargo tonnage movements between 1950 and 1969. The first premise of the rationale is that canal tonnage to and from Japan grew at an exponential rate and will continue to do so at a gradually declining rate until 1985, after which it declines rapidly and stabilizes at 100 million tons by 2010. The second premise is that all other commercial tonnage through the Panama Canal grew at an arithmetic rate and will continue to do so up through the year 2040. In order to provide an allowance for unforeseeable trends, an additional 0.5% of the total Japan and non-Japan commercial cargo is added yearly as a part of the forecast, starting with 0.5% in 1971.

The low tonnage forecast assumes that all cargo movements to and from Japan will increase from the 1969 level of 41 million tons to a maximum of 100 million tons in the year 2010. While substantial absolute growth will be experienced for the short range, a declining growth rate will result in approximately 90 million tons in the year 1985. Thereafter, the rate slowly declines to zero growth in 2010. The trend of growth of shipments to and from Japan is derived by the equation as follows:

$$Y = 100 \div 1.0 + \log^{-1} \left(\frac{\text{Year} - 1972}{13.5} \right)$$

where Y reflects millions of long tons in any designated year.

The forecast does not make a distinction between Japan's imports and exports in canal trade. However, one of the underlying assumptions is that there are predictable limits to Japan's ability to expand its export trade, especially to the United States. The absolute ceiling on interoceanic canal shipments originating in Japan would probably fall in the realm of 35 million tons by the year 2000. The major commodity being shipped from Japan would continue to be manufactures of iron and steel destined primarily for ports in the East Coast United States, East Coast Latin America, and Europe.

Another basic consideration underlying the low tonnage forecast is the assumption that the growth of shipments to Japan will level off towards the end of the century, achieving a probable ceiling of about 65 million tons per year from then on. This gives recognition to the fact that the rapid growth in canal cargo shipments to Japan was caused primarily by raw material requirements for the Japanese steel industry (coal, iron ore, and metal scrap). Japan has not had access to Asiatic mainland sources of raw materials since World War II and has had to draw upon sources in the Atlantic Basin to satisfy the burgeoning demand. In recent years, however, the Japanese steel industry has taken effective steps to obtain raw materials from the Pacific Basin, particularly from Australia and West Coast Canada. Long-term contracts have been entered into for iron ore from mines under development in Western Australia and for the opening up of mines and shipment to Japan of coal from Queensland. It is the policy of Japanese industralists to diversify the sources of supply of

their raw materials as widely as possible. It is possible, therefore, that the Japanese steel industry will reduce its dependence upon sources of raw materials that have required shipment through the Panama Canal from Atlantic ports.

The second major element of the low tonnage forecast pertains to all commercial cargo shipments exclusive of tonnage movements to and from Japan. The projection of this segment of canal traffic, which is based on a statistical analysis (using a least squares arithmetic fit) of such shipments during the period 1950-1969, amounts to approximately 118 million long tons of cargo in the year 2000. As mentioned previously, it discounts the possibility of any unusual growth of trade along specified routes other than those involving Japan.

The statistical rationale for this portion of the forecast is as follows. The growth of commercial cargo shipments through the Panama Canal to and from all regions other than Japan is well defined by the following linear relationship, determined by least squares analysis:

$$Y = 24.1 + 1.85\,(\text{Year} - 1949)$$

where Y reflects millions of long tons in any designated year. The validity of this equation is shown by the close agreement between the totals in Table IV-17 for successive five-year periods.

TABLE IV-17

COMMERCIAL TRAFFIC EXCLUSIVE OF JAPAN TRADE
(Millions of Long Tons)

Five-Year Period	Actual	Computed by Equation Y = 24.1 + 1.85 (Year - 1949)
1950 - 1954	146.7	148.2
1955 - 1959	193.2	194.5
1960 - 1964	242.6	240.7
1965 - 1969	287.7	287.0
TOTALS	870.2	870.4

Extrapolation of this growth at the same arithmetic rate results in approximately 118 million tons as the probable amount of commercial cargo through an Isthmian Canal in the year 2000 that would neither originate in nor be destined for Japan. Continued projection to the year 2040 amounts to approximately 193 million tons for this component of canal traffic.

The remaining element of the low tonnage forecast of commercial cargo comprises the cargo tonnage category that provides an allowance for unforeseeable trends. This amounts to approximately 33 million tons of commercial cargo in the year 2000 and 103 million tons in the year 2040.

Non-commercial traffic is projected at approximately 2% of commerical cargo under normal conditions (i.e., no major hostilities such as Southeast Asia).

The summary of the low tonnage forecast is depicted in Table IV-18. A more detailed summary is contained in Table A3-67 in Appendix 3.

TABLE IV-18

LOW FORECAST OF CARGO TONNAGE FOR A TRANSISTHMIAN CANAL

(Millions of Long Tons of Cargo)

Category	Fiscal Year							
	1970	1980	1990	2000	2010	2020	2030	2040
Commercial Cargo to and from Japan	41.5	79.7	95.5	99.2	100.0	100.0	100.0	100.0
Non-Japan Commercial Cargo	63.0	81.5	100.0	118.5	137.0	155.5	174.0	192.5
Unforeseeable Commercial Cargo Trends	–	8.1	19.6	32.6	47.5	63.9	82.2	102.5
Non-Commercial Cargo	7.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0
TOTAL ALL CARGO	111.5	171.3	218.1	254.3	289.5	325.4	363.2	403.0

The low tonnage forecast is considered to be unduly restrictive for long-term canal capacity planning purposes. While it has validity for conservative, alternative revenue planning purposes, it is offered as a less reasonable expectation of future interoceanic canal traffic than the potential cargo tonnage forecast. It should be noted that the growth trends of the low tonnage forecast approximate those of the potential tonnage forecast to the mid-1980s, (See Tables A3-3 and A3-67 in Appendix 3). The tonnage totals for each are about the same for the year 1985. Beyond this point the growth rate for the low forecast declines rapidly while gradually declining exponential growth characterizes the rate of growth of the potential tonnage forecast. This further illustrates the difficulty of making long-range forecasts with any assurance of precision. Broad assumptions must be relied upon as the forecast period is extended, and differing assumptions produce widely differing results.

Shipping Trends

Harbor and P t Development

The economies of scale of the superships in the transport of dry and liquid bulk cargoes are such that the provision of terminal facilities for them near the sources and destinations of such cargoes is inevitable. The next phase of the worldwide evolution of ocean transport is expected to be the modernization of port and harbor facilities, the construction of offshore terminals, and the deepening of waterways to accommodate larger carriers. This trend is already evident and pressures are mounting in the United States for greater participation in port development. A detailed discus on of U.S. and foreign port development activities is given in Appendix 4, Harbor and Port Development.

Europe already has more than a dozen ports which can accommodate ships of 100,000 DWT. The one at Ireland's Bantry Bay handles tankers of 326,000 DWT and Rotterdam will soon have accommodations near this size. Japan is already using 150,000 DWT dry bulk carriers and is planning terminals for 300,000 DWT tankers. Canada is building for 150,000 DWT coal carriers at Vancouver and is planning deep draft ports on her Atlantic coast. Australia, Brazil, and many other maritime nations have deep ports in various stages of development. The United States at present has only three ports in which a vessel of 100,000 DWT size can be fully loaded at berth. These are the petroleum berths at Los Angeles and Long Beach and a grain berth at Seattle. However, plans are in various stages of development for deep ports or off-shore terminal facilities in Maine, Delaware Bay, New Jersey, Maryland, Virginia, and Louisiana. The accommodations envisioned range from 100,000 DWT up to 250,000 DWT. United States port authorities and ship operators have recognized that the United States is at a competitive disadvantage in exporting and importing bulk commodities and are moving to close the gap. Although most existing U.S. ports cannot be economically deepened to accommodate superships, it appears certain that regional ports or off-shore deep water terminals will be developed along all three U.S. Coasts in the coming years.

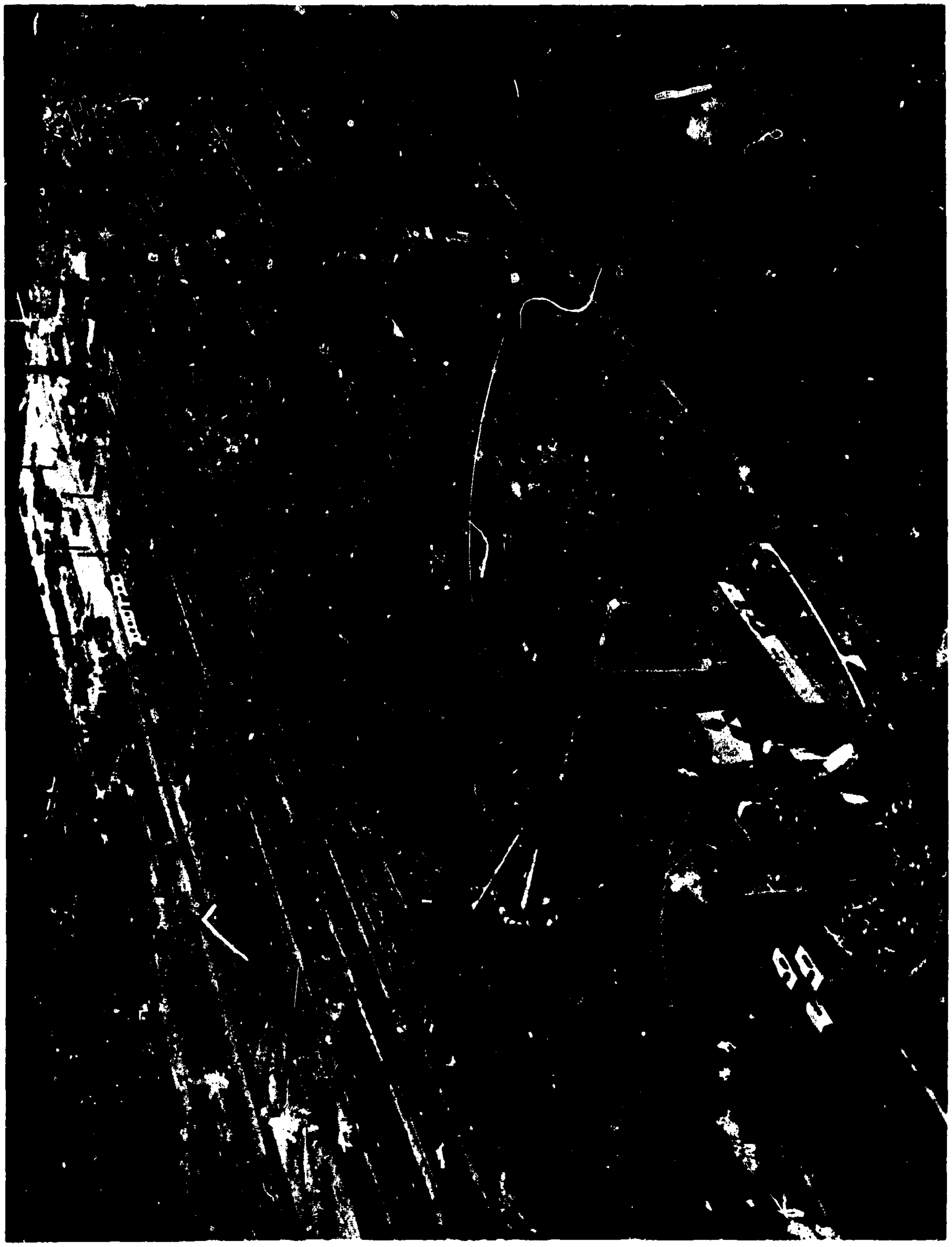
Projected Ship Sizes and Distribution for the World Merchant Fleet

As a fundamental step in the development of projections of potential canal traffic and tolls, it was necessary to forecast the sizes of ships in the world fleet and their distribution through the year 2040. Because of the extended nature of the forecast, mathematical projections of past and present ship size and ship population trends were developed and used to make the forecast. The projections were constrained where practical limitations of draft with respect to the trade were considered unlikely to change.

Using data obtained from Maritime Administration statistical summaries of the world merchant fleets and from classification society registers, values of yearly average and maximum sizes of freighters, bulk carriers, and tankers were determined and plotted. Curves of average and maximum sizes versus time were then determined by the method of least squares and projected to the year 2040. Separate curves showing the distribution of tonnage in the world fleet from 1956 through 1964 were constructed and a base distribution was fixed from the year 1960. Subsequent projections of distributions were made through the use of the ratio of the projected average to the projected maximum size, in comparison with the ratio existing in 1960.

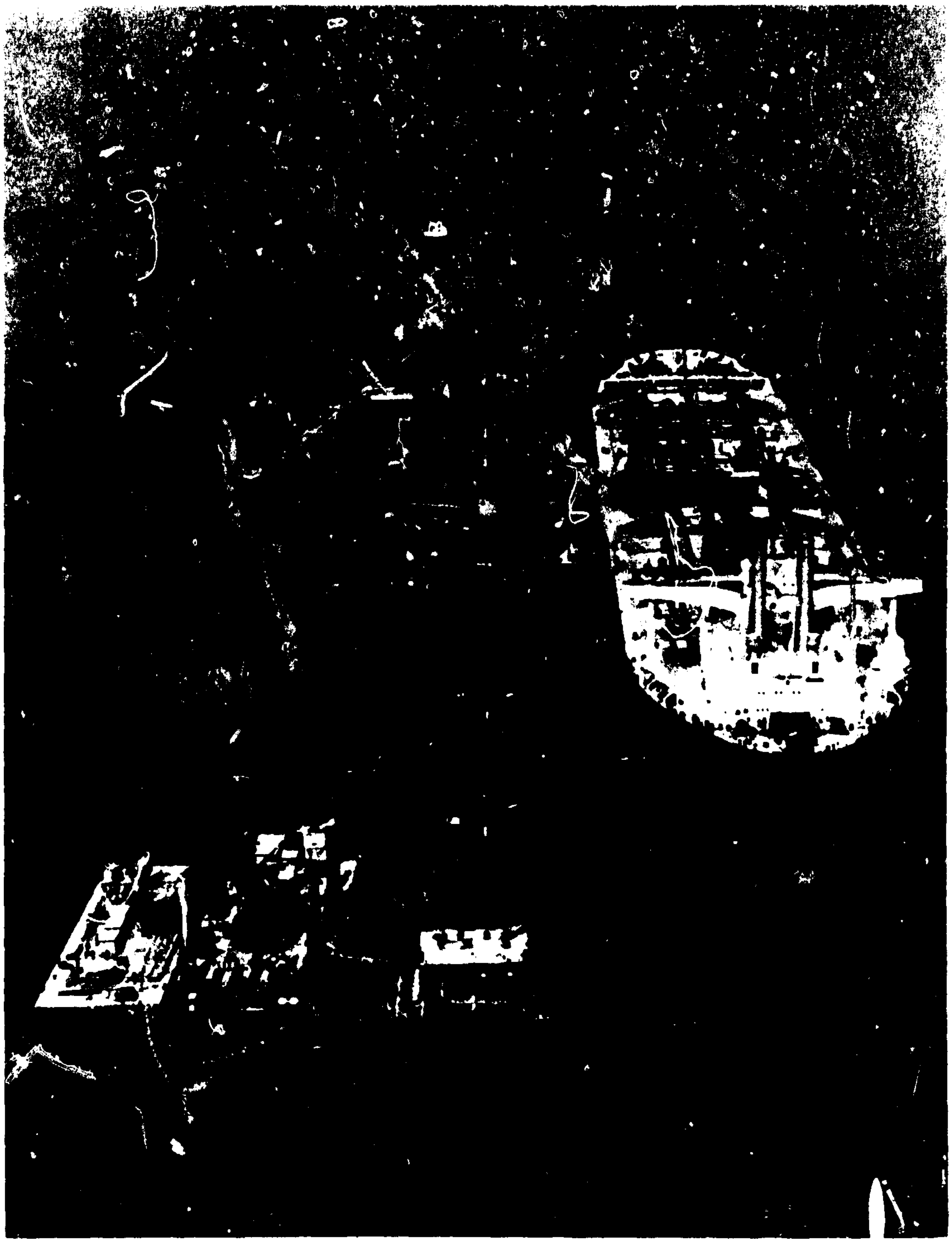
The physical constraints considered in the projections of maximum sizes are as follows: for freighters, a limiting draft of 40 ft. for harbor access in conjunction with the high

A container port at Elizabeth, New Jersey



A bulk loading operation at Long Beach, California

A tanker terminal at Long Beach, California



An offshore loading facility ten miles off the coast of Kuwait

volume of shipboard cargo space required for low-density cargo resulted in an estimated practical limit of 50,000 DWT; for tankers, a loaded draft limitation of approximately 100 ft. coupled with problems of adequate maximum size of 1,000,000 DWT; bulk carriers were considered to require access to mainland terminals for loading and unloading and were therefore load draft limited to approximately 70 ft., with a resultant maximum tonnage constraint of approximately 400,000 DWT.

It should be noted that the projection of both the average and maximum sizes are basically extensions of a best-fit smooth curve of past experience. Inasmuch as this approximates continuing zig-zag type patterns of growth in the past, it can be expected that short-term spurts of growth and subsequent slow-downs will also occur in the future and will depart periodically from the projected curves. However, on a long-term basis, it is expected that the projections will be reasonably accurate forecasts of general trends.

Tables IV-19, IV-20, and IV-21 show projected ship size distribution from 1970 through 2040 for tankers, bulk carriers, and freighters, respectively. Figures IV-5, IV-6, and IV-7 show the approximate dimensions of tankers, bulk carriers, and freighters, respectively, resulting from the deadweight tonnage figures listed in the ship size distribution tables.

Projected Ship Sizes and Distribution for Interoceanic Canal Traffic

The sizes and distribution of commercial vessels that will use a future sea-level Isthmian canal will be determined by its physical capacity, tolls, and the availability of economic, alternate routes and methods of transportation. Experience in the existing Panama Canal, the Suez Canal, and other canals world-wide has been that the largest ships that can safely use these canals do so. In the Panama Canal, the size of transiting freighters and dry bulk carriers has averaged substantially higher than the average of distribution in the world fleet below the 65,000 DWT maximum size that can transit the canal. The average size tanker is smaller.

Prior to Fiscal Year 1968, the Panama Canal commercial ocean traffic experience was recorded under four ship types – tankers, ore ships, passenger ships, and general cargo ships. Beginning in Fiscal Year 1968, the ship classes were further subdivided to report separately combination carriers, container cargo ships, dry bulk carriers, and refrigerated cargo ships in addition to ore, passenger, general cargo, and tank ships. These subdivisions allowed identification for the first time of the role of the three general ship classes established by the Maritime Administration for Tables IV-19 to IV-21 and used in this study – freighters, dry bulk carriers, and tankers. All traffic other than commercial ocean traffic identified by these three ship classes has been included in the freighter class. On the average this other traffic has the same operating characteristics as do the commercial ocean freighters (i.e., similar efficiency, average DWT, and average toll per ton of cargo). The analysis of cargo mix, ship efficiency and average toll per ton is thus largely based on Fiscal Year 1968 and the first half of Fiscal Year 1969 Panama Canal experience. The results of the 1968-1969 analysis for these four variables are given in Table IV-22. For the purposes of comparison, the records of commercial ocean traffic were examined for two ship classes, general cargo ships and tankers. The results are presented in Table IV-23.

Cargo Mix

The cargo mix is the percentages of the total annual cargo tonnage carried by each of the three general ship classes – freighters, dry bulk carriers, and tankers. The recent history

TABLE IV-19

TANKER – SIZE DISTRIBUTION

	YEAR					
	1970	1980	1990	2000	2020	2040
LARGEST (DWT) IN WORLD FLEET	326,000	762,000	1,000,000	1,000,000	1,000,000	1,000,000
AVERAGE (DWT) IN WORLD FLEET	28,960	43,000	53,400	61,700	78,300	95,300
DWT (THOUSANDS)						
Lower 25% of Ships	0-15.39	0-22.86	0-28.40	0-32.8	0-41.6	0-50.7
25 - 50% of Ships	15.39-27.27	22.86-40.54	28.40-50.30	32.8-58.1	41.6-73.8	50.7-89.8
50 - 70% of Ships	27.27-36.94	40.54-54.86	50.30-68.1	58.1-78.7	73.8-99.8	89.8-121.5
70 - 80% of Ships	36.94-44.09	54.86-65.46	68.1 -81.3	78.7-93.9	99.8-119.2	121.5-145.1
80 - 90% of Ships	44.09-56.88	65.46-84.43	81.3 -104.9	93.9-121.2	119.2-153.8	145.1-187.2
90 - 95% of Ships	56.88-69.03	84.43-102.49	104.9 -127.3	121.2-147.1	153.8-186.6	187.2-227.2
95 - 100% of Ships	69.03-326.0	102.49-762.0	127.3-1000.	147.1-1000.0	186.6-1000.0	227.2-1000.0

SOURCE: U.S. DEPARTMENT OF COMMERCE, Maritime Administration

TABLE IV-20

BULK CARRIERS — SIZE DISTRIBUTION

	YEAR					
	1970	1980	1990	2000	2020	2040
LARGEST (DWT) IN WORLD FLEET	170,000	224,000	347,000	400,000	400,000	400,000
AVERAGE (DWT) IN WORLD FLEET	16,200	21,030	25,800	30,520	39,840	49,000
DWT (THOUSANDS)						
Lower 25% of Ships	0- 5.72	0- 7.41	0- 9.09	0-10.76	0-14.04	0-17.28
25 - 50% of Ships	5.72-13.09	7.41-16.99	9.09-20.85	10.76-24.64	14.04-32.16	17.28-39.56
50 - 70% of Ships	13.09-20.37	16.99-26.43	20.85-32.44	24.64-38.36	32.16-50.08	39.56-61.60
70 - 80% of Ships	20.37-25.52	26.43-33.13	32.44-40.63	38.36-48.08	50.08-62.76	61.60-77.20
80 - 90% of Ships	25.52-33.36	33.13-43.30	40.63-53.13	48.08-62.84	62.76-82.04	77.20-100.88
90 - 95% of Ships	33.36-42.11	43.30-59.54	53.13-68.81	62.84-79.32	82.04-103.56	100.88-127.36
95 - 100% of Ships	42.11-170.0	59.54-224.0	68.81-347.0	79.32-400.0	103.56-400.0	127.36-400.00

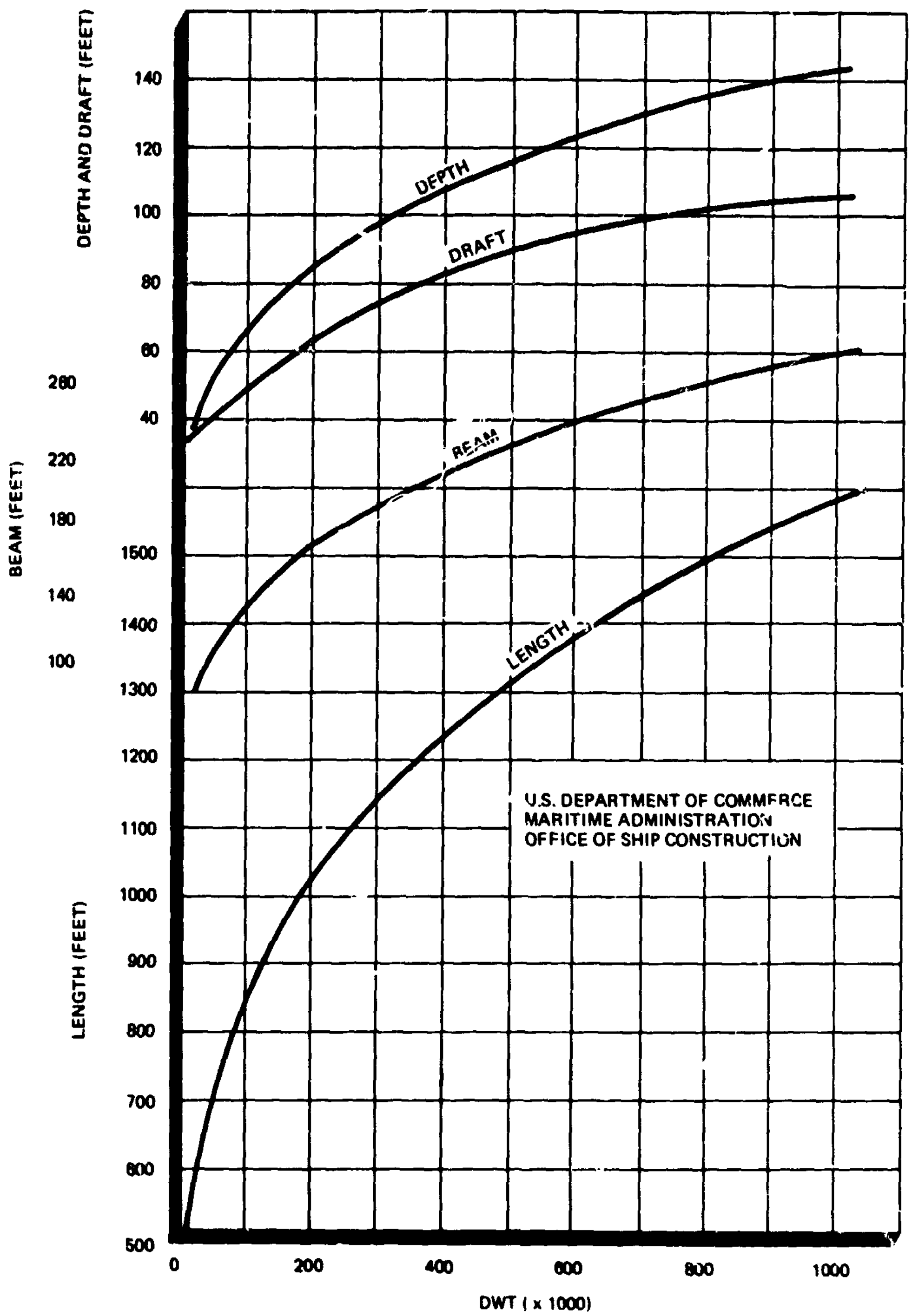
SOURCE: U.S. DEPARTMENT OF COMMERCE, Maritime Administration

TABLE IV-21

FREIGHTERS – SIZE DISTRIBUTION

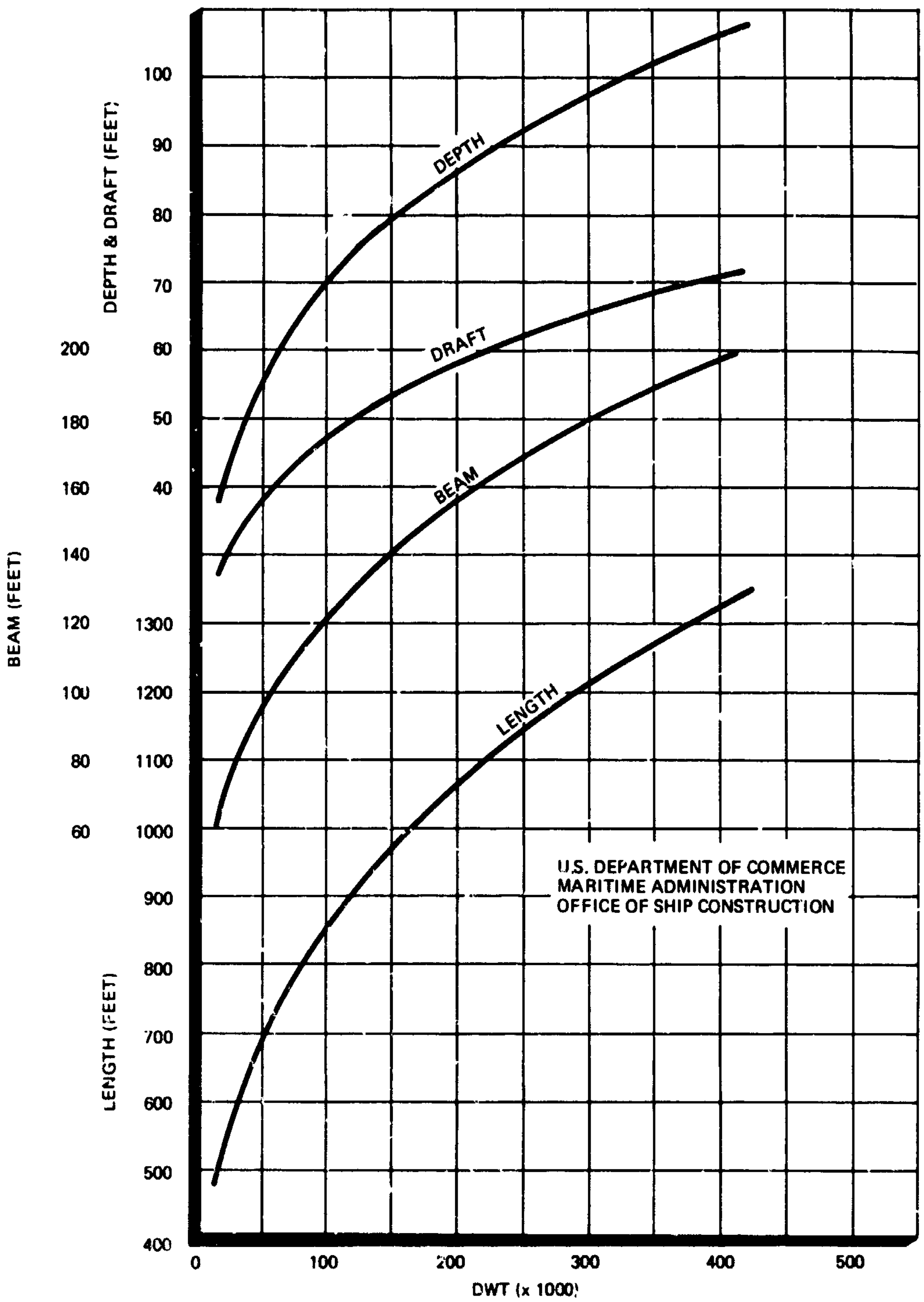
	YEAR					
	1970	1980	1990	2000	2020	2040
LARGEST (DWT) IN WORLD FLEET	25,720	33,690	44,140	50,000	50,000	50,000
AVERAGE (DWT) IN WORLD FLEET	8,090	8,590	9,130	9,700	10,000	12,350
DWT (THOUSANDS)						
Lower 25% of Ships	0- 4.67	0- 4.96	0- 5.27	0- 5.61	0- 6.32	0- 7.14
25 - 50% of Ships	4.67- 9.07	4.96- 9.46	5.27-10.24	5.61-10.88	6.32-12.27	7.14-13.85
50 - 70% of Ships	9.07-11.10	9.46-11.78	10.24-12.52	10.88-13.31	12.27-15.01	13.85-16.94
70 - 80% of Ships	11.10-11.93	11.78-12.67	12.52-13.47	13.31-14.31	15.01-16.14	16.94-18.22
80 - 90% of Ships	11.93-12.85	12.67-13.64	13.47-14.50	14.31-15.41	16.14-17.38	18.22-19.62
90 - 95% of Ships	12.85-13.73	13.64-14.57	14.50-15.49	15.41-16.46	17.38-18.56	19.62-20.96
95 - 100% of Ships	13.73-25.72	14.57-33.69	15.49-44.14	16.46-50.00	18.56-50.00	20.96-50.00

SOURCE: U.S. DEPARTMENT OF COMMERCE, Maritime Administration



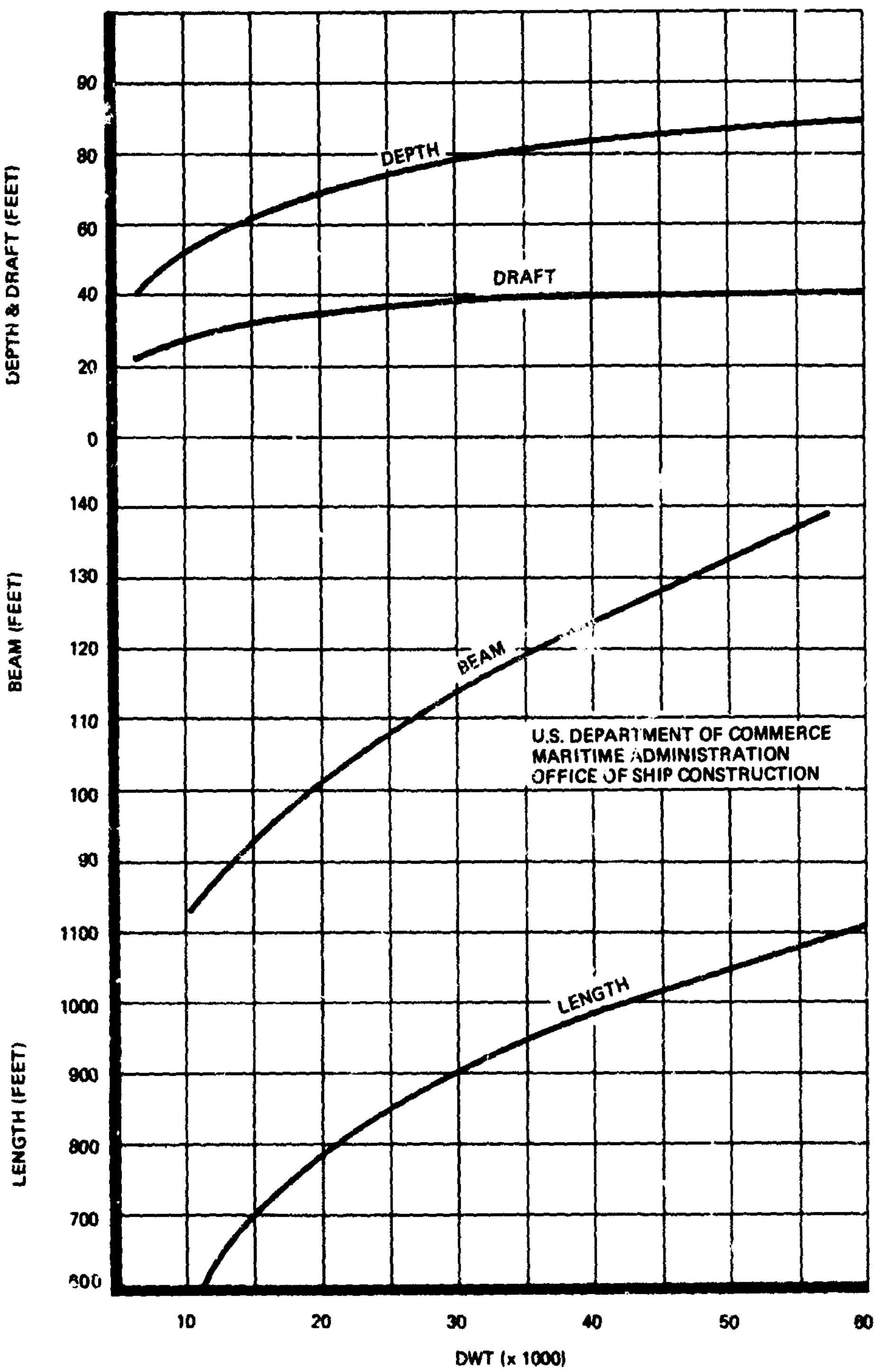
TANKER CHARACTERISTICS

FIGURE IV-5



DRY BULK CARRIER CHARACTERISTICS

FIGURE IV-6



FREIGHTER CHARACTERISTICS

FIGURE IV-7

TABLE IV-22

PANAMA CANAL EXPERIENCE FY 1968 AND FIRST HALF FY 1969

Cargo Mix (%)	FY 1968	FY 1969 (First Half)	18 Months Average
Freighters	47	45	46
Bulkers	36	39	37
Tankers	17	16	17
Efficiency (Cargo Tons/DWT)			
Freighters	.41	.41	.41
Bulkers	.70	.73	.71
Tankers	.50	.47	.49
Average DWT			
Freighters	10,600	10,600	10,600
Bulkers	26,900	27,700	27,200
Tankers	17,800	18,000	17,900
Average Toll per Ton			
Freighters	$1.12	$1.12	$1.12
Bulkers	.60	.62	.61
Tankers	.83	.87	.8[illegible]
All Ships	.88	.88	.88

NOTES: Bulkers are the dry bulk, combination dry bulk and ore ships included in commercial ocean traffic. Tankers are the tank ships included in commercial ocean traffic. Freighters are the general cargo, passenger, refrigerator, and container ships included in commercial ocean traffic, plus all other Panama Canal traffic not considered as bulkers and tankers.

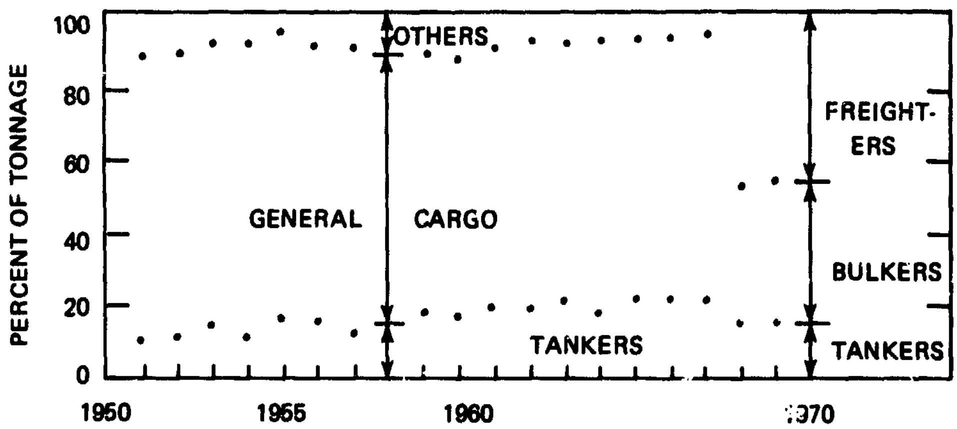
of Panama Canal commercial ocean traffic cargo mix is plotted on Figure IV-8. The tanker tonnage has shown a slow growth to a high of 22 per cent of the total transited in 1965-1967 with a nineteen year average of 17 per cent. The 1968-69 average of 17 percent has been selected for the projection of tanker cargo mix, and is assumed to remain constant throughout the period of the forecast. Figure IV-8 also shows the steady large role of the general cargo ship class until the dry bulker-freighter classification was first made in 1968. Two possible cargo mix projections were examined. The "46 per cent Freighter Mix" assumes that current trends of the mix will continue throughout the future period. This is illustrated in Figure IV-9. The "25 per cent Freighter Mix" shown in Figure IV-10 assumes a decline in the share of tonnage carried in freighters and a corresponding increase in that carried in bulkers. Assignment of an increase to tankers need not be considered since such an increase makes no significant difference in the end result of transits and revenues. The two cargo mix projections are recorded in Table A1-4. The implications of the 46 per cent mix is a relatively large number of total transits as compared to the 25 per cent mix.

TABLE IV-23

PANAMA CANAL EXPERIENCE 1951-1967 COMMERCIAL OCEAN TRAFFIC

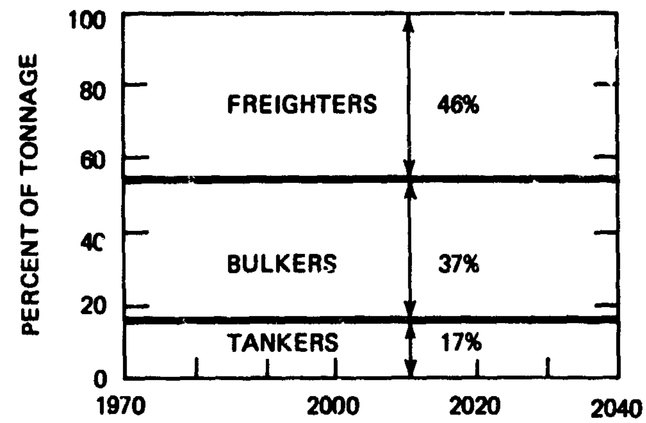
	Cargo Mix (%)[1]		Efficiency		Average DWT		Average Toll per Ton		
Fiscal Year	General Cargo	Tankers	General Cargo	Tankers	General Cargo	Tankers	General Cargo	Tankers	All Ships
1951	76	10	.53	.55	9,300	12,700	$.83	$.74	$.79
1952	77	11	.55	.50	8,900	12,500	.81	.82	.80
1953	77	14	.51	.40	9,200	13,400	.87	.99	.88
1954	80	12	.53	.42	9,200	13,200	.84	.95	.85
1955	77	16	.52	.56	9,000	13,600	.84	.74	.83
1956	76	16	.55	.55	9,200	14,900	.80	.75	.80
1957	78	12	.57	.54	9,500	15,000	.78	.76	.77
1958	74	14	.49	.49	9,600	15,900	.89	.83	.87
1959	70	18	.47	.51	9,700	16,700	.95	.80	.89
1960	60	18	.47	.55	9,700	17,800	.93	.75	.86
1961	71	19	.49	.59	10,200	19,000	.90	.72	.85
1962	73	19	.49	.59	10,600	18,800	.89	.71	.85
1963	70	21	.45	.58	10,700	17,100	.98	.72	.91
1964	72	20	.49	.61	10,700	17,600	.90	.69	.87
1965	71	22	.51	.55	11,300	18,500	.87	.76	.85
1966	72	22	.51	.55	11,900	19,300	.86	.76	.85
1967	74	22	.50	.49	12,900	20,100	.89	.84	.89

[1] Remainder of commercial ocean traffic carried in ore and passenger ships.



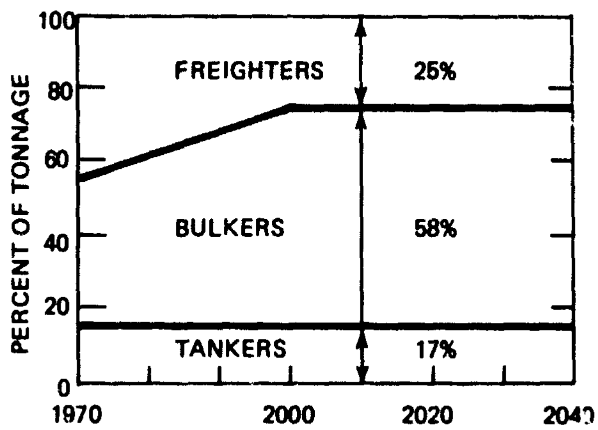
CARGO MIX – PANAMA CANAL

FIGURE IV-8



CARGO MIX 46% FREIGHTERS

FIGURE IV-9



CARGO MIX 25% FREIGHTERS

FIGURE IV-10

Ship Efficiency

A ship efficiency was assigned to each ship class by defining an index as the ratio of total annual cargo tonnage to total annual deadweight tonnage transited. Since DWT transited is not readily available for the Panama Canal, the Panama Canal Ton (PCT) was related to a deadweight ton (DWT) from a listing of 1966 Panama Canal traffic by ship name, type, PCT and DWT. The data are plotted in Figure A1-6. The relationship of PCT/DWT obtained showed that 1 PCT = 2 DWT for all major ship classes. (Exceptions: Passenger ships, 1 PCT = .6 DWT; container ships, 1 PCT = 1.1 DWT.)

Using the foregoing relationships for PCT/DWT and current Panama Canal records of PCT and total cargo tonnage, the ship efficiencies listed in Tables IV-22 and IV-23 were computed. The general cargo ship efficiency remained quite stable during the period 1951-1967 and an average of .51. The tanker efficiency varied between .4 and .6 as the relative number of ballast transits changed, with an average value of .53 for 1961-69. Although the past eighteen months average (.49) is below the nineteen year average, it is well within the range of past fluctuation, and has been assumed to prevail for the future projections. For freighters and dry bulkers, the last eighteen months averages were also used – .41 for freighters and .71 for bulkers. The long-term stability of the general cargo ship classification gives confidence to these values.

Average DWT for a Sea-Level Canal

Maritime Administration world fleet size distribution projections for each of the three types of ships are plotted in Figures A1-7, A1-8, and A1-9. The world fleet average ship size is projected to grow along line WF. The current average Panama Canal ship for each ship type is indicated at level a'-a. These average sizes were obtained from 1968-69 Panama Canal data and recorded in Table IV-22. Figures A1-10, A1-11, and A1-12 expand the portion of the previous figures in the range of the average canal ship. Again, WF – World Fleet Average Ship and a'-a is the present Panama Canal average. The growth of the average sea-level canal ship is indicated on the figures and is recorded in Table IV-24.

In the case of freighters, the present average canal freighter falls in the 33rd percentile of the world fleet distribution. This relationship is assumed to continue and the growth of the average freighter size in a sea-level canal will be along a-b, Figure A1-10. The maximum size limitations of the Panama Canal and any sea-level canal are not expected to restrain this growth.

The present average Panama Canal bulker is in the 16th percentile of the world bulker fleet size distribution. It was assumed that the average size of the bulker would grow along the 16th percentile line of that part of the world fleet smaller than the design ship (i.e., 65,000 DWT for the present canal, up to 250,000 DWT for the largest canal). Thus, the growth of the average size bulker which would pass through a sea-level canal is expected to be modified by the maximum size ship that can be accommodated by the canal. With the present lock canal size limit of 65,000 DWT, the bulker average size will grow along the line a-f, Figure A1-11. This growth is less than that for a larger canal, such as 250,000 DWT maximum ship case shown at a-b.

This same effect on growth is seen for tankers in Figure A1-12. However, in this case the present average canal tanker is in the 65th percentile. Since it is expected that the future average canal tanker will at least approach the median of that part of the world tanker fleet

which can pass through the various canal options, the percentile in which the average canal tanker is placed was changed from 65 per cent in 1970, to 60 percent in 1980, 55 per cent in 1990, and to 50 percent in 200 and thereafter.

Average Toll Per Ton of Cargo

Tables IV-22 and IV-23 record the average toll per ton of cargo for each of the three types of ships from Panama Canal experience. The average toll for the canal as a whole is obtained by weighting the individual averages by the cargo mix percentage. Table IV-25 gives the results of these computations for the two cargo mixes considered.

Transit Projections for All Canal Options for Capacity and Revenue Planning

The computations of the transit requirements for capacity and revenue planning purposes were carried out for the potential cargo tonnage forecast contained in Table IV-14, using the two cargo mixes contained in Table A1-4. For each combination of tonnage projection and cargo mix, the cargo was assumed to be carried on ships whose size was less than a given maximum ship size. This maximum size was successively established at 65,000, 100,000, 150,000, 200,000, and 250,000 DWT. The 65,000 DWT limit corresponds to the present Panama Canal. A 26,800 annual transit capacity was used for this case. For the remaining maximum ship sizes no transit capacity limitation was applied. Table IV-26 records the transit requirements for the various cases examined in connection with the potential tonnage forecast. These data are plotted in Figure IV-11. The top of each band is for the 65,000 DWT maximum ship size, and the bottom of the band is the 250,000 DWT case, with the remaining cases falling within the band.

Transit requirements were also computed for the low tonnage forecast contained in Table IV-14 for comparison purposes. However, it is emphasized that the low tonnage forecast is presented primarily to illustrate the possibility of lower revenues and to be used for an analysis in depth of the financial feasibility of a sea-level canal rather than for capacity planning purposes. Transit requirements for the low tonnage forecast are recorded in Table IV-26 and plotted with dotted lines in Figure IV-11. The low tonnage forecast assumes, among other factors, that a great volume of dry bulk cargoes in the higher potential tonnage forecast will not move through an interoceanic canal. Therefore, only the 46% freighter cargo mix is considered for purposes of transit requirements.

The following observations can be made concerning these data:

a. The maximum ship size to be accommodated makes relatively little difference in the numbers of transits required.

b. The present Panama Canal transit capacity of 26,800 annual transits is reached between 1989 and 2000 for all cases considered in connection with the potential tonnage forecast; in the case of the low tonnage forecast it is not reached until about the year 1997.

c. The cargo mix has a considerable effect on transit requirements.

Potential revenue projections related to the transit projections are discussed in Chapter V, Potential Revenue for use of a Sea-Level Canal. The detailed development of the foregoing transit projections and the associated revenue projections are contained in Appendix 1, Methodology for Computation of Projected Canal Traffic and Revenues.

It should be noted that the tonnage and traffic projections of the Potential Tonnage Forecast from years 2000 to 2040 are based on a rate of growth which is assumed to decline

TABLE IV-24

AVERAGE DWT PROJECTIONS

Ship Type	Maximum Ship Size	1970	1980	1990	2000	2020	2040
Freighter	All Limits	10,800	11,500	12,200	13,000	14,600	16,500
Bulker	65,000	27,800	33,900	39,800	44,400	48,800	52,000
	100,000	28,000	35,900	43,000	50,000	61,500	69,000
	150,000	28,000	36,000	43,700	51,600	65,800	81,000
	200,000	28,000	36,200	44,100	52,000	67,000	84,000
	250,000	28,000	36,200	44,100	52,200	67,200	85,000
Tanker	65,000	19,200	27,700	33,000	36,000	37,000	37,000
	100,000	20,000	31,800	41,600	49,200	54,300	56,000
	150,000	20,100	33,000	44,800	55,000	66,600	74,600
	200,000	20,100	33,300	45,500	56,600	71,000	83,200
	250,000	20,100	33,300	46,000	57,500	72,300	87,200

TABLE IV-25

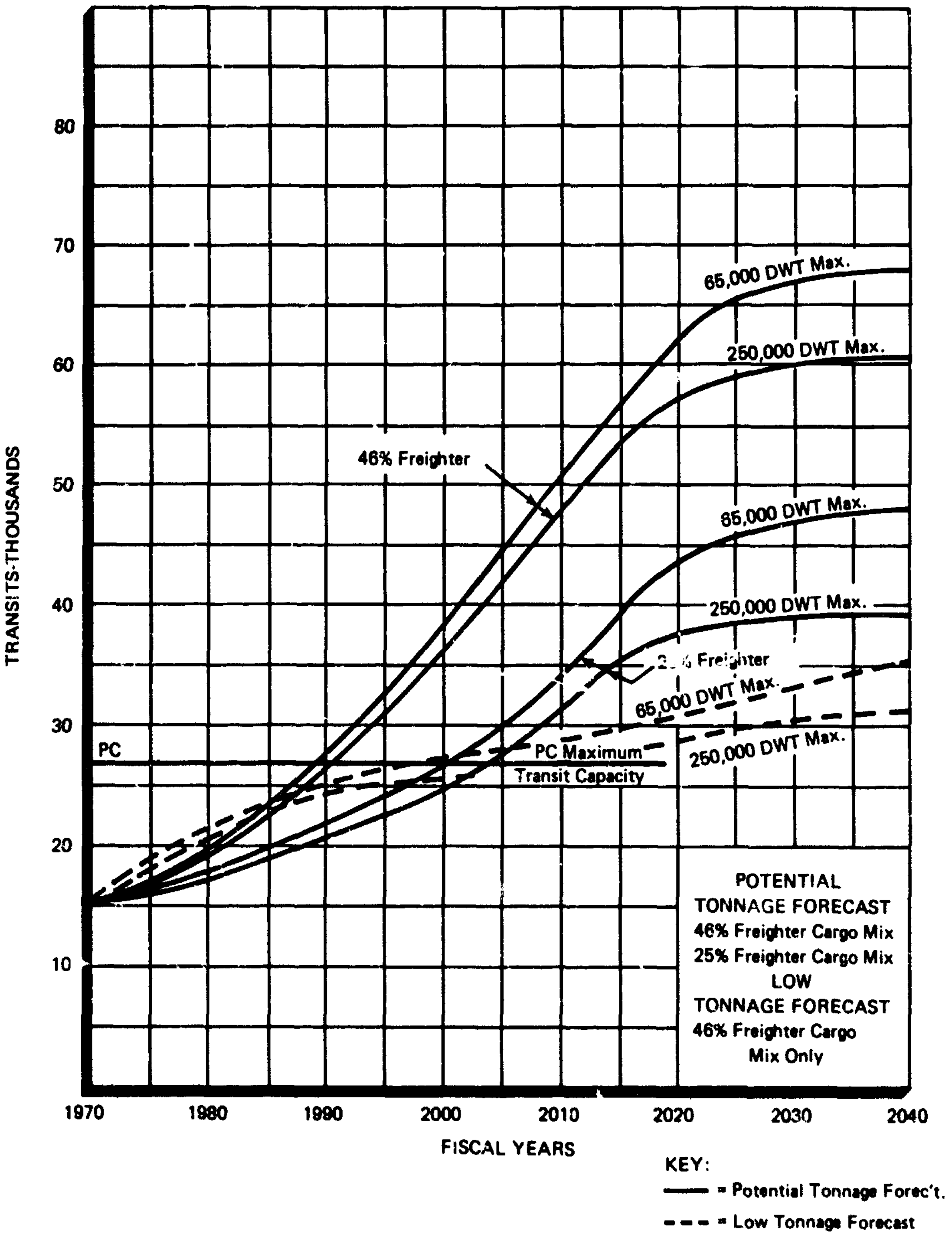
PROJECTED AVERAGE TOLL PER TON

Cargo Mix	1970	1980	1990	2000	2020	2040
46% Freighter	$.884	$.884	$.884	$.884	$.884	$.884
25% Freighter	.884	.848	.812	.777	.777	.777

TABLE IV-26

PROJECTED TRANSIT REQUIREMENTS
POTENTIAL TONNAGE FORECAST

Cargo Ship	Maximum Ship	1970	1980	1990	2000	2020	2040
46% Freighters	65,000 DWT	15,618	19,697	27,621	38,441	62,308	67,594
	100,000 DWT	15,523	19,309	26,869	37,049	58,969	6[illegible],598
	150,000 DWT	15,513	19,240	26,680	36,668	57,854	61,525
	200,000 DWT	15,513	19,213	26,626	36,577	57,555	60,973
	250,000 DWT	15,513	19,213	26,606	36,529	57,484	60,767
25% Freighters	65,000 DWT	15,561	17,823	22,116	26,754	43,647	46,2[illegible]8
	100,000 DWT	15,523	17,409	21,276	25,095	39,504	42,782
	150,000 DWT	15,513	17,339	21,069	24,649	38,187	40,215
	200,000 DWT	15,513	[illegible]	21,005	24,541	37,836	39,561
	250,000 DWT	15,513	17,310	20,985	24,486	37,756	39,323
			LOW TONNAGE FORECAST				
46% Freighters	65,000 DWT	15,618	21,453	25,194	27,350	31,493	35,220
	100,000 DWT	15,523	21,031	24,508	26,360	29,805	32,943
	150,000 DWT	15,513	20,956	24,336	26,089	29,242	31,870
	200,000 DWT	15,513	20,926	24,286	26,024	29,091	31,583
	250,000 DWT	15,513	20,926	24,268	25,990	29,055	31,477



ISTHMIAN CANAL TRANSIT PROJECTIONS

FIGURE IV-11

uniformly to zero at year 2020. The maximum number of potential transits at year 2040 under this assumption is calculated to be close to 68,000. If the rate of growth were assumed to decline uniformly to two percent at year 2040, the maximum number of potential transits at year 2040 would then be calculated to be approximately 101,400. The maximum possible demand for transits at year 2040 is therefore considered to be approximately 100,000 transits per year.

Chapter V

POTENTIAL REVENUE FOR USE OF A SEA-LEVEL CANAL

Introduction and Summary

This chapter estimates the revenue potential of a sea-level canal and evaluates the tolls system required to obtain various levels of revenue. However, no recommendation is made as to the most appropriate level of tolls or tolls system.

The estimates of potential revenues in this chapter are provided for determination of the financial feasibility of a sea-level canal. Financial feasibility is established if the projected level of revenue is greater than the cost of rendering the service. The findings are therefore not directly relevant to the much broader economic question of the value to the U.S. and the world that might be created by the construction of a new canal.

An estimate of the potential revenue based on the existing Panama Canal tolls rates can be made with a reasonable degree of confidence. However, attempting to estimate maximum revenue is a very different and complex matter involving three independent considerations: (1) the projected level of traffic; (2) the opportunity to increase the levels of tolls; and (3) the tolls structure.

The opportunity to increase levels of tolls depends upon the financial attractiveness of alternatives to the use of a sea-level canal – the sensitivity of traffic to tolls changes. Although a sea-level canal would be a unique economic undertaking, it would not be a monopoly but would compete with various alternatives. In this chapter these alternatives are evaluated and conclusions are drawn as to their effects upon the ability of a sea-level canal to achieve higher levels of revenue.

In evaluating the alternatives that could compete with a sea-level canal, it was assumed that the existing Panama Canal would either be closed or operated in conjunction with the sea-level canal under a single management. Obviously, if the existing Panama Canal were allowed to compete with the sea-level canal, it could significantly reduce the revenue potential of the sea-level canal.

Tolls systems for use by a sea-level canal vary in their ability to reflect both the costs of rendering canal service and the financial benefits accruing to the users. Accordingly, the level of potential revenue which could be collected is significantly affected by the choice of possible tolls systems. Traditionally, ships transiting the Panama Canal have been assessed charges based on their internal cubic cargo capacity. The relevance of the current tolls system to a sea-level canal is discussed in this chapter. In addition, alternate tolls structures are identified for possible application and their advantages and disadvantages are evaluated.

This chapter considers only the revenue potential of a sea-level canal. The economic consequences to the users of tolls increases, changes in the structure of tolls, and other

factors related to a new sea-level canal are only briefly considered. Obviously, tolls rates and structure changes may have detrimental effects on the users and the economics of the nations served by the Canal. However, there would also be important benefits to many users, even at higher tolls, in a canal of greater capacity than that of the present canal in both the number of transits and size of ships that can be accommodated.

As a result of the studies which are discussed in this chapter the following conclusions have been reached:

1. The traffic level forecast in Chapter IV is not likely to be achieved with a new canal limited to ships of 100,000 DWT or less. It is most likely to be achieved by a canal with a capacity to transit ships of 200,000 DWT or larger.

2. The availability of financially attractive alternatives to a canal increases as a homogenous segment of traffic, in terms of a commodity, origin or destination, grows in size. Accordingly, in a general sense the revenue potential of a single huge commodity movement is significantly less than an equal aggregate of several movements.

3. Tolls rates could be increased by an average of approximately 50% in current dollars by selective increases of varying amounts under a new tolls system designed to maximize revenues without markedly affecting traffic growth. Such a system would produce approximately 40% greater revenues.

4. In addition to the potential for increase in current dollars, average tolls could be increased at a rate to approximate the average inflation of the costs of canal alternatives with little impact on the volume of traffic.

5. The variations in tolls sensitivities among commodities, ship sizes, and routes would require modification of the present Panama Canal tolls system to attract all potential traffic to a new sea-level canal.

6. A marginal pricing system for structuring tolls would produce the maximum revenues for a sea-level canal.

Revenue Forecasts

Relationship of Traffic Composition and Revenue Potential

The traffic forecast presented in Chapter IV is by region in which it originates. For purposes of determining revenue potential, it lacks two important details: type of commodity and destination of traffic.

The attractiveness of certain alternatives, with particular application to alternative ship size and pipelines as discussed subsequently, varies significantly by commodity and by origin-destination of commodity movements. It is apparent that crude oil, coal and iron ore have the least revenue potential. In addition, the revenue potential of a sea-level canal would be less if future traffic would have disproportionate growth with respect to origins and destinations wherein the canal would have only a marginal advantage in terms of savings in days. Finally, the opportunity to use alternatives such as huge ships and pipelines varies considerably by the size of the movement. A single homogenous movement of a commodity from one source to one destination has more opportunity to avoid the canal and thus less revenue potential than a similar aggregate quantity of several movements. The present movement of U.S. coal to Japan represents a type of traffic which would offer less revenue potential.

Without details regarding the composition of future traffic, it is more difficult to make judgments of revenue potential. However, it is reasonable to assume that as the level of traffic increases, the proportionate revenue yield decreases. Accordingly, the 25% freighter mix revenue forecast (the lower revenues associated with the potential cargo tonnage forecast) presented in the following sub-section, entitled "Estimates of Revenue Potential," becomes more appropriate as the forecast grows in size. In addition, as the traffic forecast for a given point in time is increased, the revenue yield for the incremental traffic is disproportionately lower. These assumptions are reasonable because the larger the total traffic the greater the probability that it includes huge movements of the type that can most easily divert a sea-level canal. The greatest revenue potential would be produced from traffic consisting of a variety of commodities with many combinations of origins and destinations. Under this assumption, each combination of commodity, origin and destination should account for a minor portion (perhaps less than 5%) of the total traffic.

Estimates of Revenue Potential

Estimate Based on Potential Cargo Tonnage Forecast

The basis for the basic revenue forecast is the potential cargo tonnage forecast presented in Chapter IV. These long tons of cargo were extended by the average tolls yield per ton to arrive at the total forecast revenues. The revenue forecast assumes a new canal with a capacity to transit at least a 200,000 DWT ship.

The revenue forecast is made for two levels of tolls rates applying different tolls systems: (1) existing Panama Canal tolls rates and system of assessing charges or a modification thereof; and (2) estimated maximum rates in current dollars by applying a marginal pricing system. For each level of tolls, two ship cargo mixes were assumed as previously discussed in Chapter IV: (1) present Panama Canal mix of 46% freighters, 37% bulkers, and 17% tankers; and (2) possible future mix of 25% freighters, 58% bulkers, and 17% tankers. The effect of using two ship cargo mixes is to produce a probable range of revenues resulting from ship mix including composition of traffic as previously discussed.

For the existing Panama Canal tolls system and rates, one approach to tolls yield per ton of cargo would be to use the overall averages for the Panama Canal in recent years. Table V-1 presents these data for fiscal years starting with 1952. It should be noted that the yield is fairly constant during recent years reaching a low for commercial cargo of $.773 per ton of cargo in 1957 and a high of $.906 in 1963. The variation can be ascribed to two principal factors: (1) ratio of ballast to laden ships, and (2) extent to which ships are laden on weight basis.

Rather than using an overall average tolls yield per long ton of cargo, it was considered more reasonable to develop a yield rate by type of ship. This produces a range of revenue forecasts as it may be affected by ship mix. Such information is only available for FY 1968 onward and is presented in Table A1-1. The yield rate of bulkers is the lowest since these ships usually transit fully laden with cargo and have relatively few ballast transits. The yield for tankers is higher due principally to their higher ratio of ballast transits to laden transits. Although the tanker when laden with cargo is usually fully laden and is a very efficient ship for the carriage of liquids, it is an inflexible type of ship which requires a ballast return voyage. Freighters produce the highest yield per ton of cargo. Although

TABLE V-1

AVERAGE PANAMA CANAL TOLLS PER LONG TON OF CARGO TRANSITED

FY 1952 – FY 1969

Fiscal Year	Tolls Per Long Ton of Cargo	
	All Cargo	Commercial Cargo Only
1952	.824	.801
1953	.911	.884
1954	.888	.850
1955	.846	.833
1956	.809	.801
1957	.783	.773
1958	.874	.868
1959	.890	.890
1960	.858	.860
1961	.846	.850
1962	.845	.848
1963	.906	.906
1964	.867	.866
1965	.851	.855
1966	.851	.846
1967	.885	.891
1968	.883	.869
1969	.882	.863

SOURCE: Panama Canal Company Annual Reports

freighters have the lowest ratio of ballast to laden transits, they carry bulky light cargos and are often not fully laden, thus producing the higher toll yield per weight ton of cargo.

Applying the toll yield per long ton of cargo shown in Table A1-1 to the traffic forecast for the two ship mixes results in the revenues shown by the two curves for the potential tonnage forecast in Figure V-1. The lower or 25% freighter mix estimate not only reflects the possible influence of ship mix on revenues but also the possibility that lower tolls charges will be necessary to attract traffic that has financially attractive alternatives to the use of a canal.

The estimated maximum revenue is based on the ability to increase average rates by 50% while only decreasing the volume of traffic in the long term by 10% and is shown in Figure V-2. The extent of traffic loss is a function of the tolls system. Obviously a toll should not be set higher than the benefit to a ship of using the canal or the ship will not transit. However, as maximum tolls potential is approached there are practical limitations in the design of a tolls structure. It is reasonable to assume that some traffic will be lost, and 10% was considered as an appropriate estimate when a 50% increase in tolls was projected for two ship mixes.

In a similar manner to the existing level of tolls, a range of aggregate revenues is presented at maximum rates. This is necessary since few details are available as to the nature of the traffic forecast. The potential for revenues from traffic is dependent on its alternatives to the use of the canal. As discussed subsequently, the attractiveness of such alternatives varies significantly with ship routing, ship size, and type of cargo. Such details cannot be forecast so far into the future with any confidence. Therefore, the alternative to the use of a canal can only be evaluated in a range of probabilities.

Estimate Based on Low Projection of Cargo Tonnage

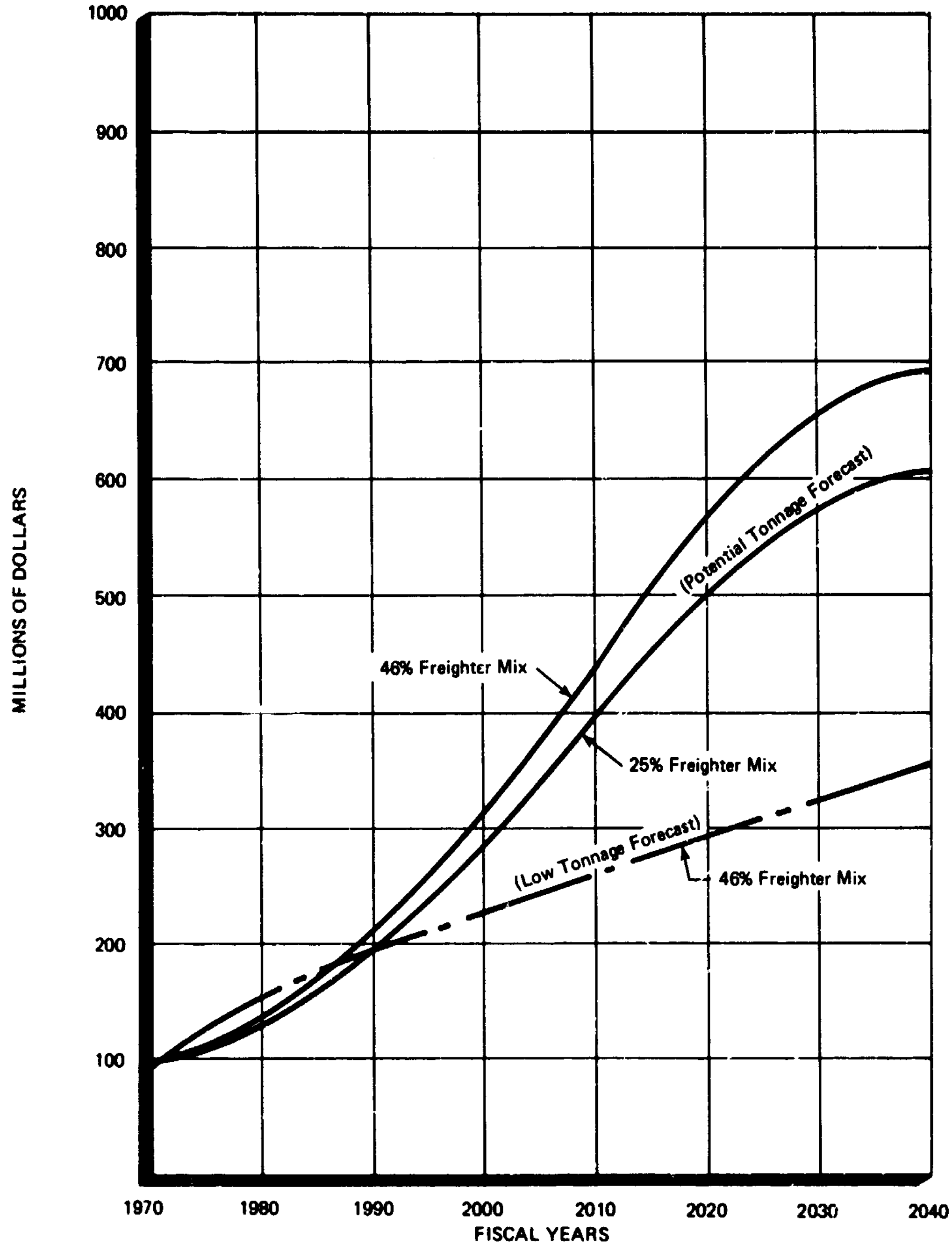
The basis for the lower revenue forecast is the low forecast of cargo tonnage presented in Chapter IV. Although the potential tonnage revenues shown in Figures V-1 and V-2 are offered as the more reasonable expectations, the lower revenues are shown to demonstrate the magnitude of possible financial risk. The methodology employed in arriving at the lower revenue estimate, which is also shown in Figures V-1 and V-2, is essentially the same as that associated with the potential cargo tonnage forecast. However, the lower cargo tonnage forecast on which it is based assumes, among other factors, that a great volume of dry bulk cargoes in the higher potential tonnage forecast will not move through an interoceanic canal. Therefore, only the 46% freighter cargo mix is considered for purposes of the lower revenue estimation.

Tolls Sensitivity

Synopsis

In one sense an Isthmian canal has an absolute monopoly on a service for ships that must pass between the Atlantic and Pacific oceans by the shortest route. However, an Isthmian canal competes with many other means of achieving the same economic result. This competition consists not only of alternative ship routing and larger ships, but also competing modes of transportation and alternate sources and markets. The term "tolls sensitivity" is used herein to describe the potential to increase tolls before the traffic is lost. (This is known to economists as "price elasticity.")

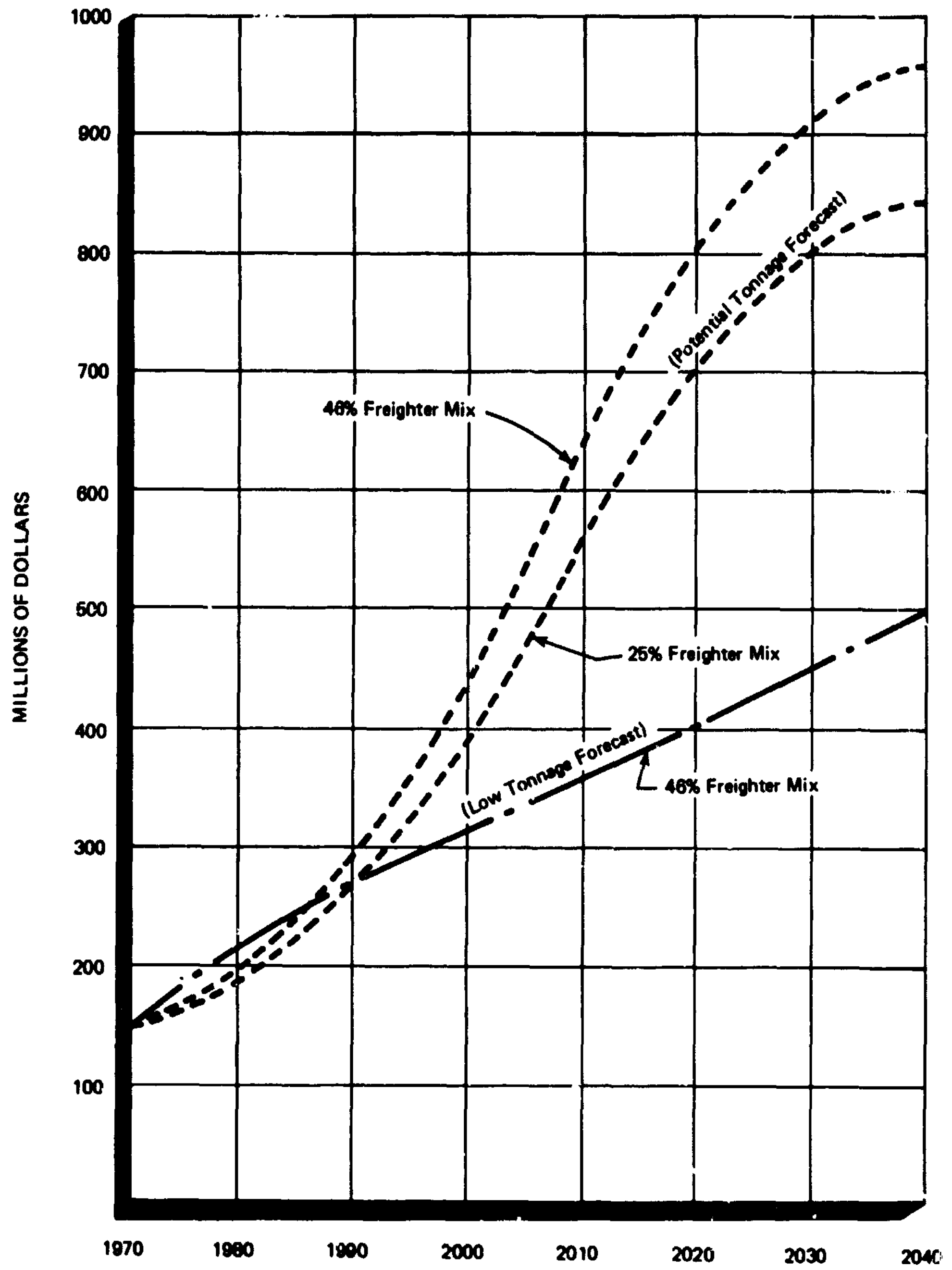
The question often asked in evaluating the value of the existing Panama Canal is, "How much would it cost a ship to go around South America?" This question assumes that the decision to transit the Panama Canal is not made until the ship reaches the approaches of the Canal and that the only alternative is around South America. Quite obviously, before a ship leaves its port the decision on the route to be followed is determined based on the costs involved, including Panama Canal tolls. Possibly less apparent but more important is that the cost of tolls is considered before a ship is built, a contract to sell is signed, banana trees are planted, or iron ore mines developed.



*Assumes a canal with no limitations on number of transits and with capacity to transit ships up to 200,000 DWT.

POTENTIAL ANNUAL REVENUES*
BASED ON CURRENT PANAMA CANAL RATES

FIGURE V-1



*Assumes a canal with no limitation on number of transits and with capacity to transit ships up to 200,000 DWT.

POTENTIAL ANNUAL REVENUES*
BASED ON MAXIMUM REVENUES POTENTIAL APPLYING NEW TOLLS SYSTEM

FIGURE V-2

The alternatives to the use of a sea-level canal place an upper limit on the canal's ability to charge for its services. An evaluation of these alternatives is made subsequently in this chapter. The following is a brief description of the alternatives:

1. Alternative Ship Routing: This is the most obvious way to avoid use of a canal. Its attractiveness varies by route. For example, ships originating on the West Coast of Panama destined for the East Coast of the United States have little opportunity for rerouting. In contrast, ships originating in the Philippine Islands destined for the East Coast of the United States gain only a marginal advantage by using an Isthmian canal and consequently could easily be rerouted.

2. Alternative Ship Size: The economies of scale may make alternate ship routing more attractive with increases in ship size. With the present Panama Canal limited to ships of about 65,000 DWT, alternate routing with ships double that size can be economically attractive. However, the economies of scale of ship size tend to level off beyond 200,000 DWT; thus, depending upon the capacity of the sea-level canal, this alternative may have limited application.

3. General Shipping Services: Shippers operating general cargo ships on scheduled routes cannot usually select alternative routes or use superships economically. However, they can minimize the payment of tolls by other means. For example, traffic originating in the United States Midwest can either go to the United States East Coast or West Coast by other transportation means for ocean transportation service to Asia. In response to tolls increases, traffic moving to the United States East Coast could be diverted to the United States West Coast.

4. Alternative Transportation Modes: There are several alternative transportation modes which can substitute for canal service. These include a trans-Isthmian pipeline, super aircraft, and rail service.

5. Alternative Sources and Markets: In order for traffic to transit an Isthmian canal, it requires that the seller be on one side of the canal and the buyer on the other. There are commodities where a rearrangement of buyers and sellers could be made to reduce the use of the canal. For example, Peruvian and Chilean iron ore sold in Europe now transits the Panama Canal. Europe could obtain more of its iron ore from sources on the East Coast of Canada and Brazil with a corresponding reduction in canal transits.

6. Alternative Development: Raw materials are the dominant traffic through the canal in terms of volume. Some of these commodities are available in several places in the world and development of a source involves the evaluation of all costs including tolls. In response to tolls increases developers could choose sources that eliminate the need for using an Isthmian canal.

During its history the Panama Canal has had a fairly dramatic example of a loss of traffic due to a competing alternative. During the early years of the Panama Canal, U.S. intercoastal cargo represented approximately 55% of the total commercial tonnage transiting the canal. United States railroads have effectively competed for this traffic and in Fiscal Year 1969 it comprised only 3.8 per cent of Panama Canal commercial cargo. (Alaska and Hawaii are included in data for West Coast U.S.)

There are various contradicting but ostensibly valid arguments as to why present Panama Canal tolls are either insignificant or significant in an economic decision. Arguments which maintain that Panama Canal tolls are insignificant include:

1. Tolls represent a very minor portion of the selling price of commodities. To illustrate: For a ship carrying automobiles the toll is approximately $7 per automobile or only .35 per cent of a selling price of $2,000.

2. Tolls are only a small percentage of transportation costs and the minimization of transportation costs may not result in maximum profit to a user. To illustrate: The development of crude oil involves enormous investment in exploration and development costs. These are sunk costs which the developer hopes to recover through the sale of crude oil. Obtaining the crude oil after development is complete almost literally involves the mere turning of a valve; thus, an oil company may willingly pay large transportation costs including tolls if a sale can be made.

3. Tolls rates in dollars have remained basically unchanged since the canal opened in 1914. Since that date, there has been significant inflation which effectively has reduced the tolls in terms of real dollars.

Arguments indicating that present tolls rates are significant include:

1. For low value commodities, the tolls represent a significant percentage of the delivered cost. To illustrate: For crude oil selling for $10 a ton Panama Canal tolls are approximately $.70 a ton, representing 7% of the delivered cost.

2. Tolls represent a significant amount of a ship's operating cost, and the percentage increases as the ship size increases. To illustrate, for foreign flag ships operating between the East Coast of the United States and Japan, which is the most important route in volume of cargo moving through the Panama Canal, the following comparison is made for bulk carriers.

	Operating Cost*		Tolls	
Ship DWT	Daily	Total One Way Voyage	Amount	% of Cost
25,000	$3,600	$ 90,000	$11,000	12%
50,000	4,800	120,000	20,000	17%
100,000	6,000	150,000	40,000	27%

*Includes cost of capital investment and all other costs except tolls. The 100,000 DWT is included since it could use a new sea-level canal; however, it cannot transit the present canal.

The arguments regarding the significance or insignificance of Panama Canal tolls do not place them in proper perspective. In the long run, the willingness of a user of a canal to pay tolls will depend almost solely upon the cost of alternatives. Minimization of any cost can substantially increase a canal user's profit. Accordingly, each will take tolls into consideration as one factor in his decision. The availability of alternatives to the use of the canal varies significantly not only among commodities but also among shipping companies, shippers, and combinations of buyers and sellers. The issues are so complex that only generalizations can be made at present, let alone making extrapolations into the distant future.

The discussion below examines in detail previous studies of Panama Canal tolls sensitivity and the alternatives to the use of a canal based on the economics of known technologies. In summary, the studies of the various alternatives to the use of a canal as they relate to the revenue potential of a canal indicate the following:

1. Alternate Ship Routing: This alternative is not a significant factor either in maintaining existing Panama Canal tolls rates or in increasing rates by 100% or more for ships up to 50,000 DWT and by 25% for larger ships.

2. Alternate Ship Size: The significance of this alternative varies with the ship size capacity of the new canal. If a sea-level canal is limited to 100,000 DWT ships a significant portion of potential future commodity movements would probably move in larger ships on alternative routes. A canal which could accommodate ships of 200,000 DWT or larger would be needed to attract the potential cargo tonnage forecast in Chapter IV at the present average tolls levels. However, this may require selective decreases in tolls for the large ships using the canal through either a new tolls system or modification of the existing Panama Canal system.

3. Petroleum Pipeline: This is an attractive alternative for large movements of crude oil. Substantial tolls decreases may be necessary to retain large crude oil movements if they develop.

4. Slurry Pipeline: This is an attractive alternative for solids such as iron ore, which can be economically moved in slurry form. Tolls decreases may be necessary to attract large new movements of such solids if they develop in the future.

5. Land Bridge and Railroads: Availability of this alternative does not preclude canal tolls increases of 100% or more.

6. Aircraft: Availability of this alternative does not preclude canal tolls increases of 100% or more.

7. Non-transportation Alternatives: It is not possible to measure the limitations on tolls created by such alternatives as developing new sources and markets that would eliminate or limit use of a sea-level canal.

It appears probable that the present Panama Canal tolls rates could be increased as much as 50% on an average basis without markedly affecting projected traffic growth. This would require application of a tolls system which permitted selective increases and decreases with rates for some categories of cargo possibly increasing 150%. Inevitably, some loss of potential traffic would occur. This loss should not exceed 10%. Accordingly, a 50% increase in rates would produce 40% more revenues for a future canal that could accommodate ships of at least 200,000 DWT. Higher increases in tolls rates may be possible, but estimating the response by users to increases in tolls of the magnitude necessary to obtain much higher revenues is probably beyond the scope of economics or any other discipline.

There is further reason why average tolls increases beyond 50% were not considered. From an economic viewpoint, the purpose of constructing a sea-level canal is to render a service of value to world shipping. Increases beyond 50% in tolls are not only impossible to evaluate, but if required, could substantially eliminate a major economic justification for investment in a sea-level canal.

Previous Studies of Tolls Sensitivity

There have been two relatively recent studies of the sensitivity of the existing Panama Canal traffic to tolls increases. The A.D. Little Company conducted a study in 1965 for the

Republic of Panama that measured the possible effects of tolls increases. This study was undertaken in an attempt by Panama to justify higher annuity payments from the United States. The study was limited to the short-run effects of tolls increases on 1963 traffic, given substantially the conditions existing in 1963. The methodology used to measure the ability to increase tolls was least-cost ship routing with the largest ship studied only 45,000 DWT in size. Specific qualifications were made in the report that no study or conclusions were being made regarding the possible long-range effects of tolls increases. The report concluded that tolls could be doubled or perhaps tripled with little short-term effect on the volume of traffic. It further concluded that at such levels of increase there could be long-run responses which might significantly reduce the level of traffic. Because the report is limited to evaluating the short-run effects, given conditions existing in 1963, the conclusions overstate the ability of a sea-level canal to increase tolls. A forecast for a sea-level canal necessarily involves concern for long-range effects and certainly must consider the existence of ships far larger than 45,000 DWT in size.

The other recent study of Panama Canal tolls sensitivity, which was completed in 1967, was made by the Stanford Research Institute (SRI). This is the only comprehensive study of the long-term effect of tolls increases on traffic. SRI identified the various alternatives to the use of the Panama Canal previously discussed. The study concluded that the sensitivity of traffic to tolls increases varied by commodity with maximum possible increases ranging between 25% and 150%. An across-the-board increase of 25%, using the existing tolls system, would produce 16% more revenue; and the maximum increase in revenue of 36% over 20 years was possible with a tolls structure varying the tolls rate by commodity.

By making certain adjustments, it may be possible to make some determination of the sensitivity of the sea-level canal traffic to tolls increases based on this SRI study. It should be recognized that since the Panama Canal is limited to a ship size of approximately 65,000 DWT, its traffic is more sensitive to tolls increases than a sea-level canal. This is because the existing canal is vulnerable to the economies of scale available with larger ship sizes using alternate routes. This can be illustrated by the following example of a 50,000 DWT foreign flag ship using the Panama Canal versus a 150,000 DWT ship using the Cape of Good Hope, where both ships have originated on the East Coast of the United States bound for Japan.

50,000 DWT		150,000 DWT
25	Voyage days	38
$ 4,800	Daily operating costs	$ 7,000
	Voyage costs –	
$120,000	Ship operations	$266,000
20,000	Tolls	–
$140,000	Total	$266,000
45,000	Cargo tons	135,000
$ 3.11	Voyage cost per long ton	$ 1.97

The foregoing example demonstrates that the existing Panama Canal is vulnerable to the use of super ships using alternative routing. Even if the Panama Canal were tolls-free, it

would cost $2.67 per ton of cargo using the 50,000 ton ship versus $1.97 for the larger ship. As a matter of fact, the Japanese are currently constructing 150,000 DWT bulk carriers for use in carrying coal from the East Coast of the United States to Japan via the Cape of Good Hc

Even though the 150,000 DWT ships are currently being built to avoid the limited draft existing Panama Canal, these ships would use a sea-level canal at present or even higher tolls rates. The saving to a ship in using a sea-level canal in the above illustration would be 13 days at sea (38 versus 25) or $91,000 in operating costs ($7,000 daily operating costs times 13 days). At existing rates of tolls this ship would pay $60,000 or would have a net saving, using the sea-level canal, of $31,000. Accordingly, tolls could be increased 50% before the cost of using a sea-level canal would be equal to the cost of the alternate longer route.

In those cases where SRI identified alternate ship size as a limiting factor for increasing tolls, a sea-level canal would be in a position to charge a higher toll. The following is a list of commodities which SRI identified as having tolls sensitivity because of super ships using alternate routing and its estimate of the rate increases which would produce maximum revenue over 20 years:

Commodity	Present Rate Increase
Coal	25%
Phosphate Rock	100
Iron Ore	25
Soybeans	100
Petroleum	50
Grains	100

An upward adjustment of the revenue potential for these commodities is required to relate SRI's findings to a sea-level canal. When this adjustment is made, the SRI study appears to support the conclusions regarding the potential to increase revenues contained elsewhere in this report.

Regarding inflation, SRI indicated that it cannot be automatically assumed that tolls can be increased to the extent of inflation with effect on traffic volume. However, it is apparent that to the extent that canal tolls are limited by alternate transportation modes, tolls can be increased to the extent of the inflationary impact on the alternative without any effect on traffic volume. For example, as the costs of constructing and operating ships increases due to inflation, the ability of a canal to increase tolls also increases.

Comparative Transportation Economics

It is a basic conclusion of this report that the potential cargo tonnage forecast presented in Chapter IV will be transported in world oceanborne trade between origins and destinations that could gain advantage by using an interoceanic canal. The relevant question is then: Will the traffic be shipped through a canal? This question can be substantially answered by reference to the economics of various transportation modes, including, of course, oceanborne transportation. In the long-term, the transportation system that is least costly will be used to transport the tonnage.

The canal is part of a transportation system. Its economics are tied to water transportation which, fortunately for a canal, has costs among the lowest of all transportation modes. For other transportation modes to compete against water transportation requires the presence of overwhelming cost factors other than transportation costs.

Table V-2 presents a summary of the comparative costs of transportation modes. The amounts shown are not intended to be precise but are reasonable estimates so as to present a valid comparison among the various transportation modes. It is readily apparent by a review of Table V-2 that water transportation has a substantial advantage over other transportation modes not only for bulk commodities but also for general cargo. The closest competition for bulk commodities comes from pipelines.

The subsequent sections of this report review the possible competitive position of alternative transportation modes to the use of a water transportation system involving the use of a canal. In addition, an evaluation is made of the possibility of using water transportation not involving the use of the canal by either alternative ship routing or alternative ship routing combined with larger ship sizes than a canal could transit.

Alternative Ship Routing

The most apparent alternative to the use of a canal is a different ship routing. It is probably also the alternative that can be evaluated with the greatest degree of confidence since all dimensions of the problem remain the same except the longer voyage at sea.

The attractiveness of different ship routing is probably limited to bulk commodities originating at a single port and destined for a single port or group of ports within close proximity to one another. Ships in linear service (general cargo) call on many way-ports in an attempt to maximize their utilization of capacity. The location and sequence of way-ports can limit significantly the ability of such ships to alter their routing.

Table V-3 presents a summary of the relationship of ship size to the advantage of a sea-level canal over the best alternate route. Listed are the major routes using the present Panama Canal and the long tons of cargo that transited in Fiscal Year 1969.

The best alternate route is indicated for each route, along with the additional miles and voyage days at 16 knots, to use of the Panama Canal. In determining the best alternate route it was assumed that the Suez Canal would be open and that its tolls would be the same as present Panama Canal tolls. (Suez Canal laden tolls have been approximately the same as Panama Canal tolls for most ship types in recent years.) The columns in the right of the schedule present four ship sizes (50,000; 100,000; 200,000; and 250,000 DWT), and the percentage increase (decrease) in present Panama Canal tolls necessary to equalize the cost of the route using the Panama Canal with the cost of the best alternate route. This summary assumes that the same ship is using the sea-level canal or the best alternate route. Accordingly, a specific ship size is only applicable if the sea-level canal can transit a ship of that size. For example, if the maximum size ship an assumed sea-level canal can transit is 200,000 DWT, then the amounts for 250,000 DWT ships are not applicable.

Table V-3 supports the following conclusions regarding the relationship of a sea-level canal and alternate routes:

1. As the difference in miles between the canal route and the alternate route increases, the potential to increase tolls increases.

TABLE V-2

COMPARATIVE COSTS FOR TRANSPORTATION MODES

Transportation Mode	Range of Charges Cents/Ton Mile	Comments
Water – bulk commodities	0.01 – 0.2¢	Based on costs of foreign flag ships 20,000 DWT and over.
Water – general cargo	0.2 – 1.0+	Wide range but most tonnage is being transported at lower end of cost range.
Pipeline – petroleum	0.2 – 0.5	Volume over 2 million tons a year and distance over 300 miles.
Pipeline – slurry	0.3 – 0.5	No preparation and separation. Volume over 2 million tons a year and distance over 300 miles.
Pipeline – slurry	0.7 – 1.1	Preparation and separation included.
Railroad	0.4 – 0.9	Unit train rate. No return load.
Railroad	0.9 – 2.0+	Based on operating costs excluding return on capital. Wide range but high end not significant in terms of tons carried.
Truck	3.0 – 8.0	One way haul. No return load.
Aircraft	4.0 – 15.0	Lowest amount is either Lockheed L-500 or Boeing 747 operating under optimum conditions.

NOTE. No loading or unloading charges included.

TABLE V-3

RELATIONSHIP OF SHIP SIZE AND ALTERNATE ROUTE TO TOLLS FOR THE MAJOR ROUTES USING THE PANAMA CANAL FY 1969

Route	Panama Canal FY 1969 Long Tons of Cargo (Millions)	Best Alternate Route: Route	Panama Canal Advantage: Miles	Panama Canal Advantage: Days	By Ship DWT — Percent Increase (Decrease) in Tolls to Equalize Cost of Alternate Route: 50,000 (Daily operating cost $ 4,800) (Tolls at present rate $20,000)	100,000 ($ 6,000) ($40,000)	200,000 ($ 8,000) ($80,000)	250,000 ($ 9,500) ($100,000)
East Coast U.S. – Japan and Korea	34.8	Cape Good Hope	5,400	13.0	212%	95%	30%	23%
Europe – West Coast U.S. and Canada	7.6	Cape Horn	5,600	13.5	224	102	35	28
South America–Intercoastal	4.0	Cape Horn	3,700	8.5	104	27	(15)	(19)
U.S.–Intercoastal	3.9	Cape Horn	7,900	19.5	368	192	95	85
East Coast U.S.–Colombia, Ecuador and Peru	3.8	Cape Horn	6,200	15.0	260	125	50	42
Europe–Colombia, Ecuador and Peru	3.8	Cape Horn	4,000	9.5	128	74	(5)	(10)
East Coast U.S.–Philippine Islands and Formosa	3.4	Suez Canal	–	–	0%	–	–	–
		Cape Good Hope	2,300	5.0		(25)	(50)	(53)
East Coast U.S.–Chile	3.4	Cape Horn	5,000	12.0	188	80	20	14

TABLE V-3

RELATIONSHIP OF SHIP SIZE AND ALTERNATE ROUTE TO TOLLS FOR THE MAJOR ROUTES USING THE PANAMA CANAL FY 1969 (Cont'd)

Route	Panama Canal FY 1969 Long Tons of Cargo (Millions)	Best Alternate Route: Route	Panama Canal Advantage: Miles	Panama Canal Advantage: Days	By Ship DWT Percent Increase (Decrease) in Tolls to Equalize Cost of Alternate Route: 50,000	100,000	200,000	250,000
West Indies–West Coast U.S.	2.9	Cape Horn	5,900	14.5	248%	117%	45%	38%
West Indies–Asia	2.8	Suez Canal	4,900	13.0	212	—	—	—
		Cape Good Hope	5,900	14.5		117	45	38
Europe–Oceania	2.6	Suez Canal	—	—	0	—	—	—
		Cape Good Hope	1,500	2.0		(70)	(80)	(81)
East Coast S. America–West Coast U.S.	2.5	Cape Horn	5,900	14.5	248	117	45	14
East Coast U.S.–Oceania	2.4	Cape Good Hope	2,800	6.5	56	(3)	(35)	(38)
Europe–Chile	1.4	Cape Horn	2,[illegible]00	5.5	32	(17)	(45)	(48)
Other routes	22.1							
	101.4							

NOTES: (1) Transit time for Panama and Suez Canals of one day assured.
(2) Additional voyage days calculated based on 16 knot ship.
(3) Daily operating costs include all costs of operation and return on capital for foreign flag tanker or bulk carrier.
(4) Suez Canal route cannot transit laden ship of the 100,000 DWT size or larger.

2. As the ship size increases, the attractiveness of alternate routing to avoid tolls also increases, demonstrating the economies of scale. The economies of scale curve based on present technology falls very rapidly for ships less than 100,000 DWT, flattening out between 100,000 and 200,000 DWT, and thereafter falls slowly. (Refer also to Figure V-3 which includes a curve showing the number of voyage days in present rates of tolls by ship size.)

3. As ship operating costs increases the potential for a canal to increase tolls and retain the traffic increases proportionately. This is not shown directly on the table but can be deduced from the data shown.

For most routes and ships sizes, Table V-3 supports the conclusion that tolls can be increased by varying percentages up to approximately 200% in current dollars before the traffic is lost. The benefit to the user of the canal route varies by route and ship size indicating that greater revenues could be obtained if a pricing system were to differentiate by type of traffic in assessing tolls. The application of a system of tolls differentiating charges by type of traffic is discussed in detail in the next part of this chapter.

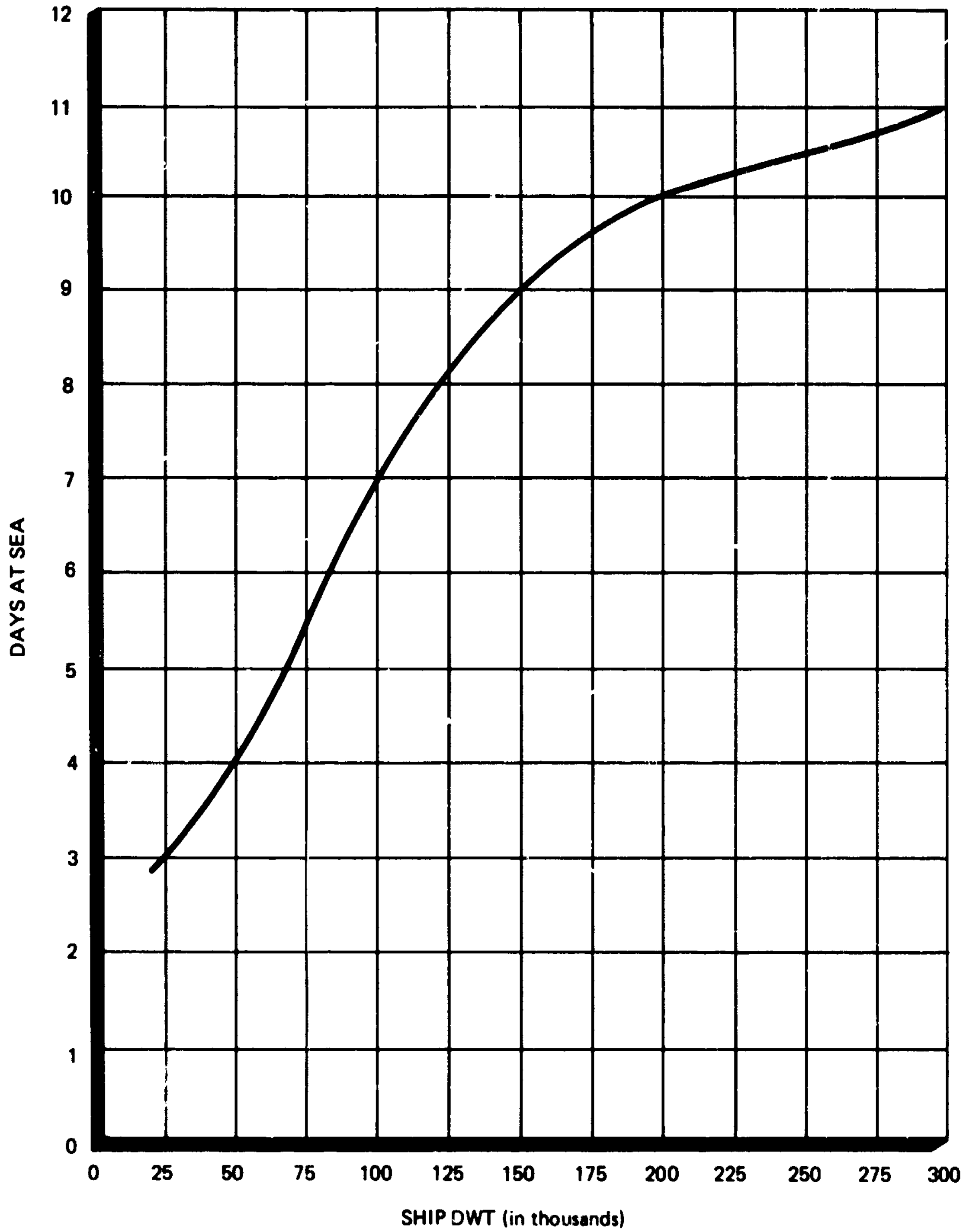
The foregoing analysis is limited to the one-way voyage as contrasted with the round trip. This approach is considered valid since the availability of a back haul cargo is not influenced by the routing selected for the inbound cargo. The financial attractiveness of using a route including a canal requiring the payment of tolls, or an alternative route, should be analyzed separately for each leg of the round-trip voyage.

The possible use of the Northwest Passage has recently received considerable publicity. A test voyage completed by a tanker demonstrated that it is physically possible to move a ship from the North Slope of Alaska to the East Coast of the U.S. Based on information currently available, the financial feasibility of the route has not been established for even huge ice-breaking tankers specially constructed for the hazards of the ice. Furthermore, it is considered remote that the route will ever be used in regular commercial trade. Accordingly, it was not included among the possible alternative routes evaluated above.

Alternative Ship Size

The financial attractiveness of a different ship route can be enhanced by using ship sizes larger than those that could transit an Isthmian canal. The evaluation of this alternative is more difficult than simply evaluating the same ship size on an alternative route. In addition to transit capacity of a canal, significant factors influencing the selection of ship size include the capacity of ports to accommodate larger ships and the desire of sellers and buyers to deal in larger unit transactions. For example, a shipment of 250,000 tons of wheat is unheard of in present economics. In a manner similar to the discussion of alternative ship routing, the application of alternative ship size is probably limited only to certain bulk commodities.

There has been a spectacular increase in the size of both tankers and bulk carriers within recent years as is illustrated by Table V-4. Based on tankers now in operation and on order, approximately 50% of the DWT capacity of the world's fleet, but only 10% of the number of ships, is represented by ships of 100,000 DWT or more. For dry bulk carriers, 12% of the DWT capacity now in operation or on order, but only 2% of the number of ships, is represented by ships 100,000 DWT or larger. This development of super ships has been based principally on the economies of scale. For example, the 25,000 DWT tanker has



EQUIVALENCE OF DAYS AT SEA OPERATING COST
TO PRESENT PANAMA CANAL TOLLS
FIGURE V-3

TABLE V-4

THE WORLD'S MERCHANT FLEET
HISTORY OF SHIPS 100,000 DWT AND OVER

SUMMARY OF ALL SHIPS

Year	100,000 to 124,999	125,000 to 149,999	150,000 to 199,999	200,000 to 249,999	250,000 to 299,999	300,000 to 349,999	350,000 and Over	TOTAL
Put in operation								
1959	2	–	–	–	–	–	–	2
1960	1	–	–	–	–	–	–	1
1961	–	–	–	–	–	–	–	–
1962	1	1	–	–	–	–	–	2
1963	1	–	–	–	–	–	–	1
1964	3	–	–	–	–	–	–	3
1965	9	–	–	–	–	–	–	9
1966	16	5	1	1	–	–	–	23
1967	20	2	4	1	–	–	–	27
1968	23	5	12	15	–	2	–	57
	76	13	17	17	–	2	–	125
On order as of 12/31/68	29	34	37	124	43	4	1	272
TOTALS	105	47	54	141	43	6	1	397

TABLE V-4

THE WORLD'S MERCHANT FLEET
HISTORY OF SHIPS 100,000 DWT AND OVER (Cont'd.)
By Ship Type

Ship Type	100,000 to 124,999	125,000 to 149,999	150,000 to 199,999	200,000 to 249,999	250,000 to 299,999	300,000 to 349,999	350,000 and Over	TOTAL
Tankers								
Put in operation 1959-1968	69	12	17	17	–	2	–	117
On order 12/31/68	17	12	24	124	43	4	1	225
TOTALS	86	24	41	141	43	6	1	342
Dry Bulk Carriers								
Put in operation 1959-1968	7	1	–	–	–	–	–	8
On order 12/31/68	12	22	13	–	–	–	–	47
TOTALS	19	23	13	–	–	–	–	55
TOTALS	105	47	54	141	43	6	1	397

a daily operating cost of approximately $3,600 whereas the ship 8 times that size has a total daily operating cost of approximately $8,000 or only somewhat more than doubling of cost. Table V-5 presents a summary of ship operating costs and present tolls by ship DWT for foreign flag ships. The range of daily operating costs by ship size tends to illustrate the possible influence of future inflation. The economies of scale tend to flatten out beyond 200,000 DWT and there are other reasons to believe that ships in larger numbers will not be built beyond that size.

Avoiding canal tolls by using an alternative route with a ship larger than that which a canal could accommodate is relevant if the economies of scale are particularly strong for the ship sizes larger than the canal can accommodate. This was previously discussed in reference to the existing Panama Canal with its limitation of ships up to approximately 65,000 DWT.

Table V-6 summarizes the relationship of canal transit size capacity and the financial attractiveness of using alternative routes and ship sizes. The table presents data for four canal sizes: 100,000; 150,000; 200,000; and 250,000 DWT transit ship size. For each such assumed canal size, an analysis is given for the following variables:

1. Canal route has an advantage over an alternative route of 5, 10, and 15 days based on using a 16 knot foreign flag ship.
2. Ship size used on the alternative route is 150,000; 200,000; 250,000; and 300,000 DWT.

In each case for the route using the canal a voyage time of 20 days was assumed. Thus, if the canal route has a 5 day advantage the alternative route requires 25 days.

If a canal is limited to a transit size capacity of 100,000 DWT ship, there is a clear indication of the financial attractiveness of alternative routes and ship sizes. For most ship sizes and range of canal advantage in days over an alternative route, even the elimination of tolls results in the alternative route being financially advantageous.

If the canal can transit ships up to 150,000 DWT, it can compete with alternative ship routes and ship sizes. However, it should be noted that decreases in current tolls levels may be necessary on certain routes to retain the traffic. A canal that can transit ships of 200,000 and 250,000 DWT easily competes with alternative routing and ship size. For such large transit size canals, competition would only come from routes where the canal had a marginal advantage of about 5 days. These routes do not currently contribute significant amounts of traffic to the present Panama Canal.

Table V-6 assumes that in every case the voyage through the canal requires 20 days. As a matter of convenience in the analysis, 20 days were selected since this voyage time is representative of the greatest number of routes using the present Panama Canal. However, it should be pointed out that as the voyage time for the canal route decreases the financial attractiveness of alternative routes with larger ship sizes also decreases. A separate analysis of this has not been prepared because the effect is minor in comparison with the effect of either ship size or difference between canal route and alternative route in voyage days.

For this analysis, ship sizes were limited to a maximum of 300,000 DWT. No ship substantially beyond that size is either in operation or on order today. Thus, the data available on such ships are limited. However, there is a clear indication, based on present ship construction technology, that the economies of scale are small beyond 300,000 DWT. Even ocean depths in some areas present constraints to ships beyond that size. It is probable

TABLE V-5

COMPARISON OF TANKER OPERATING COSTS WITH PANAMA CANAL TOLLS

Ship Size DWT	Operating Cost of[a] Daily	Operating Cost of[a] 5 Days	Operating Cost of[a] 13 Days	Present Tolls[b]
25,000	$ 3,600	$18,000	$ 46,800	$ 11,000
	4,000	20,000	52,000	
	4,400	22,000	57,200	
50,000	4,800	24,000	62,400	20,000
	5,300	26,500	68,900	
	5,800	29,000	75,400	
75,000	5,500	27,500	71,500	30,000
	6,000	30,000	78,000	
	6,500	32,500	84,500	
100,000	6,000	30,000	78,000	40,000
	6,500	32,500	84,500	
	7,000	35,000	91,000	
150,000	7,000	40,000	104,000	60,000
	7,500	42,500	110,500	
	8,500	47,500	123,500	
200,000	8,000	45,000	117,000	80,000
	9,000	50,000	130,000	
	10,000	55,000	143,000	
250,000	9,500	50,000	130,000	100,000
	11,000	55,000	143,000	
	12,000	60,000	156,000	
300,000	11,000	55,000	143,000	120,000
	12,500	62,500	162,000	
	13,500	67,500	175,500	

[a]Lowest amount is estimated maximum 1968 cost, highest amount is about 20% above 1968 cost. The high amount will be reached well before 1980 if the industry figure of a 3% per year compounded increase in operating cost continues. Estimates include provision for all costs of operation and return on capital for foreign flag tankers.

[b]Tolls determined on present Panama Canal system and rates for laden transit.

TABLE V-6

RELATIONSHIP OF CANAL TRANSIT SIZE CAPACITY AND ATTRACTIVENESS OF USING ALTERNATIVE ROUTES AND LARGER SHIPS

Alternative Route				By Canal Transit Size Capacity Percent Inc (Dec) in Tolls to Equalize Cost[1]			
Canal Advantage In Days [2]	Ship Size DWT	Voyage Cost Total	Voyage Cost Per DWT	100,000	150,000	200,000	250,000
5	150,000	$175,000	$1.17	(107)%	(40)%	7%	2%
5	200,000	200,000	1.00	(150)	(82)	(50)	(40)
5	250,000	238,000	.95	(162)	(95)	(62)	(52)
5	300,000	275,000	.92	(170)	(102)	(70)	(60)
10	150,000	210,000	1.40	(50)	17	50	60
10	200,000	240,000	1.20	(100)	(32)	–	10
10	250,000	285,000	1.14	(115)	(47)	(15)	(5)
10	300,000	330,000	1.10	(125)	(57)	(25)	(15)
15	150,000	245,000	1.63	7	75	107	117
15	200,000	280,000	1.40	(50)	17	50	60
15	250,000	332,000	1.33	(67)	–	32	42
15	300,000	385,000	1.28	(80)	(12)	20	30

NOTES: (1) This is the percentage increase (decrease) in the present rate of Panama Canal tolls necessary to equalize the one-way voyage cost of DWT capacity of the largest ship that can transit the assumed canal size with the alternative route and ship size.

The cost of the canal route including tolls, by ship size is as follows:

Ship Size	Voyage Cost Total	Voyage Cost Per DWT
100,000	$160,000	$1.60
150,000	200,000	1.33
200,000	240,000	1.20
250,000	290,000	1.16

(2) Difference in voyage days between canal and alternative route. In each case, the canal route was assumed to be 20 days.

that future ships larger than 300,000 DWT will be few in number and limited to specific routes. Such ships should have little influence on canal tolls policy.

The foregoing discussion again emphasizes the potential advantage to a canal in differentiating tolls by type of traffic. Even at present tolls levels, tolls on a 200,000 DWT ship would be $80,000. The magnitude of charges at that level presents the opportunity for alternatives to the use of a canal. An Isthmian canal would need to carefully determine the level of charges to be made against large ships if they are to be attracted to canal usage and if the construction of ship sizes too large to transit the canal is to be limited.

Petroleum Pipeline

Crude oil and petroleum products have been and are expected to continue to be significant commodities shipped through a canal. If they continue to constitute approximately 17% of all traffic, 60 million tons of the potential traffic projection for the year 2000 will be of this category. Because of the importance of petroleum and its products for a new canal, consideration must be given to the opportunity this traffic would have to use a pipeline – an obvious alternative to a canal. The first analysis below treats a theoretical large capacity pipeline of a size built to transport huge quantities of crude oil over a long period of time. The second treats the recent proposal to construct a pipeline across Panama in 1971, to be operated by the Panamanian Government.

Theoretical Large Capacity Pipeline

The possibility is remote that a trans-Isthmian pipeline would attract petroleum products. The pipeline operating problems, extensive storage facilities and difficult ship scheduling problems associated with transporting a ariety of petroleum products through a pipeline system would significantly increase costs. Consideration of a pipeline is thus limited to use for crude oil, which currently accounts for about 7% of Panama Canal traffic. As previously discussed, the traffic forecast does not identify commodity movements. Thus, no specific estimate of crude oil traffic in the year 2000 is provided. However, a continuation of the growth pattern and mix of random crude oil and petroleum products movements of the past 20 years would leave considerably more than half the petroleum tanker tonnages not subject to replacement by pipeline movements.

The major U.S. petroleum companies have expressed the opinion that a sea-level Isthmian canal able to accommodate large tankers would be used on a random basis, as is the present canal, but that its construction cannot be justified on the basis of the requirements for petroleum movements alone.

Because of its permanence and lack of flexibility, a pipeline must be based on broad forecasts as to the flow of oil over a particular route for many years ahead. In the appraisal of the value of alternative transport methods, a trans-U.S. pipeline may play a major role in transporting Alaskan North Slope crude oil to U.S. Midwest and East Coast markets should use of the Northwest Passage by ice-breaking tankers prove infeasible.

At present, it costs approximately 11.2¢ per barrel of crude oil to transit the Panama Canal in a fully laden tanker assuming a ballast return. The toll cost for a one-way transit is approximately 6.4¢ per barrel. However, most of the existing crude oil traffic through the Panama Canal is a two-way traffic, i.e., the laden transit is matched by a ballast transit. Thus, the effective rate is about 11.2¢ per barrel.

To accommodate a huge movement of crude oil and to be as competitive as possible with a sea-level canal, a trans-Isthmian pipeline would need an annual capacity of approximately fifty million long tons. Construction costs for such a pipeline are detailed in Table V-7. Operating costs, based on various assumptions on cost of capital and utilization as well as the amortization period for the project are shown in Table V-8.

The cost of capital was calculated both for 8% and 10% interest rates, and this is believed to be a reasonable range. The amortization period was set at 20 years. With a 40 year amortization period, the annual amortization and total annual costs would decrease approximately 16% and 10%, respectively. Included in the operating cost is a tax to the Republic of Panama of 22¢ per long ton. The original draft treaty that was negotiated between the United States and Panama in 1967 provided an annuity for Panama from the Panama Canal of 22¢ a long ton and this amount has been included in the estimated cost of operating a new canal. It was assumed that whether the Republic of Panama or private interests constructed a pipeline across the Isthmus Panama would insist on some amount of tax and 22¢ a long ton was selected as a reasonable estimate. It would not be economically logical for the Republic of Panama to allow traffic to be diverted from the canal, where it earns 22¢ a ton, to a pipeline where it earns less.

The optimum operating situation for a pipeline is a single major movement. If one assumes that such a movement involving full utilization of the pipeline takes place, the resultant cost would be 9.13¢ per barrel at the 8% cost of capital. No additional cost is applicable for the loading and discharge of ships. Loading and discharge rates of 15,000 bbl/hr are practical, making it possible to limit the delay time to one day for a ship. This is approximately the same delay time which a ship experiences using a canal. Accordingly, a round trip voyage through the canal, laden in one direction and in ballast for the return, involves the same lost time as loading and discharging the tankers through a trans-Isthmian pipeline.

Less efficient utilization of a pipeline would result from random usage by several origin and destination movements. Under these conditions the total utilization of the pipeline is assumed to be 20% less or 40 million long tons annually. This results in a pipeline cost of 10.62¢ per barrel at 8% cost of capital. The shipper may also incur the additional costs involved in obtaining two ship charters rather than one in a random type use of a pipeline. Another consideration would be that if the shipper also owned the ship, as is the case of integrated petroleum companies, there may be strong cost advantages to having the ship continue through the canal rather than chartering an additional ship for use on the other end of the pipeline. Both of these factors could add significant cost to the use of a pipeline on a random basis but quantifying this cost is difficult.

The opportunity for a backhaul movement for a ship using the canal could completely change the economics of a pipeline to strongly favor the canal. An example can best illustrate this point. The assumed facts are: (1) crude oil is being moved in large quantities between the West Coast of South America and the East Coast of the U.S. and in the reverse direction a large quantity of grain is being moved; and (2) the tankers using a pipeline could not obtain the backhaul grain cargo. Under these circumstances, the pipeline would have little opportunity to compete for the crude oil even if the canal were to increase tolls substantially.

TABLE V-7

TRANS-ISTHMIAN PIPELINE
ESTIMATED CONSTRUCTION COSTS
ANNUAL CAPACITY 50,000,000 TONS

Pipeline	
Includes water crossing, poor terrain, pumping, and bridges. 42" – 48" line, 40 miles long at $650,000/mile.	$ 26,000,000
Terminals	
Includes submarine pipeline or dredging Atlantic and Pacific ports with two berths each for 326,000 DWT tankers in 90' – 100' water.	50,000,000
Storage	
For crude oil and ballast water. Locations at both Atlantic and Pacific ports. 7,000,000 BBL storage at each location at $2.00/BBL.	28,000,000
Total Construction	$104,000,000
Other	
Engineering at 10%	$ 10,400,000
Legal and administrative	2,000,000
Interest during construction and contingencies at 15%	15,600,000
Total	$132,000,000

TABLE V-8

TRANS-ISTHMIAN PIPELINE
ESTIMATED CHARGE PER BBL

	Annual Utilization			
	50,000,000 Tons 100% Capacity Cost of Capital*		40,000,000 Tons 80% Capacity Cost of Capital*	
	8%	10%	8%	10%
Total Cost Annually				
Construction cost of $132,000,000 recovered over 20 years	$13,150,000	$15,550,000	$13,150,000	$15,550,000
Operation and maintenance	7,800,000	7,800,000	7,800,000	7,800,000
Total	$20,950,000	$23,350,000	$20,950,000	$23,350,000
Cost per BBL	5.99¢	6.67¢	7.48¢	8.34¢
Panama tax	3.14	3.14	3.14	3.14
Total cost per BBL	9.13¢	9.81¢	10.62¢	11.48¢

*Amortization period 20 years.

Pipeline Proposed by Consortium

The following discussion evaluates a recently proposed pipeline across the Isthmus of Panama. In January 1970, a consortium of British and German interests announced a preliminary agreement with the Government of the Republic of Panama for the construction of a crude oil pipeline. This development poses a threat to the petroleum traffic currently using the Panama Canal and must be considered in any decision to build a sea-level canal.

The competitive environment of the existing Panama Canal, limited to ship sizes up to approximately 65,000 DWT, differs greatly from that of a sea-level canal with capacity to transit much larger ships. For sufficient volumes of traffic, the economies of scale of ship sizes beyond the size that can transit the existing Panama Canal become attractive. This is a principle previously discussed in the Section entitled "Previous Studies of Tolls Sensitivity" as well as the Section entitled "Alternative Ship Size."

Based on information publicly released regarding this proposed pipeline; the following data are available:

(1) The pipeline will be 30 inches in diameter with a daily capacity of 700,000 barrels or 100,000 long tons.

(2) There will be storage capacity for six million barrels.

(3) Tankers will berth to single berth moorings connected by submarine pipeline to the storage facilities. The draft at moorings will permit tankers up to 120,000 DWT.

(4) The Republic of Panama will own and operate the pipeline which will be financed by the consortium over a 10-year period.

(5) The capital cost of the facilities is estimated at $80,000,000.

(6) No operating cost data were announced for the pipeline but it can be assumed that it will be only moderately less than for the larger capacity pipeline previously discussed. Accordingly, an annual operating cost of $7 million has been assumed.

Based on the foregoing facts and assumptions the cost per barrel of output can be estimated. Similar to the previous analysis of the larger capacity pipeline, an 8% and 10% cost of capital over a 20-year amortization period will be assumed. The cost per barrel has been estimated based both on maximum daily capacity of 700,000 barrels and on 80% capacity or 560,000 barrels. This results in annual utilization of 36,500,000 tons and 29,200,000 tons, respectively, as shown in Table V-9.

This analysis indicates that the cost of the proposed pipeline is about the same as for the larger capacity pipeline previously described. However, the proposed pipeline does not have the same facilities in that it can only accommodate a 120,000 DWT ship and has storage for 6,000,000 barrels vs. accommodation for a 326,000 DWT ship and 14,000,000 barrel storage for the larger pipeline.

There are two sources of traffic which appear available to this pipeline at the present time. The first source would be the West Coast of South America including developments in Bolivia, Peru, Equador and Colombia. The development of sources of crude oil in Equador and Colombia are recent and publicized reports have indicated that the quantities involved will increase substantially over the next few years. The obvious market for this crude oil is the U.S. East Coast and Europe since it is reported that the recent discovery of oil in Alaska's North slope will fulfill the requirements of the U.S. West Coast.

A second source of traffic for this proposed pipeline would be oil from the Alaskan North Slope. This is domestic U.S. crude oil with a cost premium over crude oil available from foreign sources. It is reasonable to assume that all production will be for consumption within the U.S. The obvious initial market will be the crude oil-short West Coast of the U.S. A trans-Alaskan pipeline is to be constructed from the North Slope of Alaska to the southern Alaskan port of Valdez. From this point the oil will be moved by tanker to U.S. West Coast ports.

Based on estimates of possible production rates in the North Slope, it is projected that the production will exceed the requirements of the U.S. West Coast and therefore the excess will need to move to the U.S. Midwest and East Coast. There have been extensive studies undertaken by the various oil companies involved on how to transport this oil to the U.S. Midwest and East Coast. The most widely publicized has been the MANHATTAN project involving the conversion of the tanker MANHATTAN into an ice breaking ship for testing of the Northwest Passage as a route to be used. Because of the extensive costs

TABLE V-9

TRANS-ISTHMIAN PIPELINE – CONSORTIUM PROPOSAL ESTIMATED CHARGE PER BBL

	Annual Utilization			
	100% Capacity 36,500,000 Tons Cost of Capital*		80% Capacity 29,200,000 Tons Cost of Capital*	
Total Costs Annually	8%	10%	8%	10%
Construction cost of $80,000,000 recovered over 20 years	$7,900,000	$9,420,000	$7,900,000	$9,420,000
Operation and maintenance	7,000,000	7,000,000	7,000,000	7,000,000
TOTAL	$14,900,000	$16,420,000	$14,900,000	$16,420,000
Cost per BBL	5.83¢	6.43¢	7.29¢	8.03¢
Panama Tax	3.14	3.14	3.14	3.14
Total Cost per BBL	8.97¢	9.57¢	10.43¢	11.17¢

*Amortization period 20 years.

involved in this project, it can be assumed that the oil companies anticipate possible substantial benefits from this route. If the Northwest Passage proves to be economically unfeasible, an alternative is a trans-U.S. pipeline. The crude oil would move from Valdez by tanker to Seattle and then to Midwest and East Coast markets via pipeline. According to reports made public by oil companies, the most costly transportation system for moving Alaskan crude oil would be via tanker and a trans-Panama pipeline.

The economic advantages of using a trans-Panama pipeline vary considerably when comparing movements of crude oil originating on the West Coast of South America with those originating on Alaska's North Slope. With respect to crude oil originating on South America's West Coast, it is a relatively short distance from Equador, Colombia and Panama to the pipeline. Even the approximate 2,000 miles from Panama to New York requiring approximately 5 days at sea is considered relatively short for the utilization of super-ships. For this reason, the pipeline is placed in direct competition with the Panama Canal without additional advantage of the economies of scale of larger ship size. It is concluded that for

this traffic the pipeline will be unable to charge a rate higher than the tolls cost for using the Panama Canal or approximately 11¢ per barrel. Depending on the assumptions made regarding the cost of capital and the amortization period for the project, the advantage of the pipeline over the canal tends to be marginal. In arriving at this conclusion, a 3.14¢ tax to Panama has been included in that Panama may receive such an amount for traffic utilizing the Panama Canal at some future date.

The advantage of the Panamanian pipeline to the Alaskan North Slope crude oil is a much more complex matter to analyze. The conclusions of the oil companies that in the long term the Northwest Passage or a trans-U.S. pipeline will be the most economical method of reaching Midwest and East Coast markets has been accepted for purposes of this analysis. Therefore, the trans-Panama pipeline has a potential place for this crude oil only in the short term. Specifically, this period would start when North Slope production exceeds requirements of the U.S. West Coast for any one oil company and that company has need for the oil on the U.S. East Coast. The period would extend until it would be advantageous to employ the more capital intensive alternatives of using the Northwest Passage route, if feasible, or the trans-U.S. pipeline. Depending on the circumstances in which the oil companies find themselves and their individual judgments as to the future, this period could be very short or could extend for several years. In this regard, the oil companies may either act independently of each other or as a group. The group approach is illustrated by the joint investment of the oil companies involved in the trans-Alaska pipeline. Even if the facts presently known to the oil companies were available for analysis, it would probably be impossible to make a judgment at this time as to how long the temporary period would extend during which the trans-Panama pipeline would be utilized.

It is possible to analyze the advantage of a trans-Panama pipeline over the Panama Canal during the temporary period when oil companies will need to move crude oil to the East Coast U.S. before either the Northwest Passage or a trans-U.S. pipeline is employed. The advantage of the trans-Panama pipeline is substantial as is shown by the following analysis comparing the use of a 65,000 DWT ship transiting the Panama Canal and a 120,000 DWT ship utilizing the trans-Panama pipeline.

When the economies of scale of large ship sizes can be brought to bear, the trans-Panama pipeline enjoys a substantial advantage over the existing Panama Canal. This has been illustrated for the transportation of the North Slope oil. In contrast, when the ship sizes that utilize the pipeline can also transit the Panama Canal, which may be the case for the West Coast South American crude oil, the pipeline has only a marginal advantage. The decision to build the trans-Panama pipeline at this time will be dependent on the amount of utilization which can be assured from the shippers of North Slope oil. Based on information that has been publicly released, the consortium that has proposed the trans-Panama pipeline is now in the process of attempting to obtain contracts from the various oil companies. Results of these discussions are not available at this time.

Petroleum Pipeline – Conclusions

The following conclusions regarding the possible effect of a crude oil pipeline on the revenue potential of a sea-level canal have been reached:

(1) If a sea-level canal were available for transit, the proposed trans-Panama pipeline probably would not be constructed were tolls set at the present or moderately lower levels.

	Alternative Routing	
	Panama Canal 65,000 DWT	**Panama Pipeline 120,000 DWT**
Daily Operating Cost	$ 10,400[1]	$ 13,000[1]
Required Days Between Valdez, Alaska and New York		
7,000 miles at sea @ 16 Knots	36	36
Panama Canal transit round trip	2	
Mooring, discharging and loading 2 ships	–	4[2]
Total days	38	40
Cost of Voyage		
Ship cost	$395,200	$520,000
Panama Canal tolls	46,800	–
Total Cost	$442,000	$520,000
Cargo in barrels	413,000	770,000
Cost per barrel	$ 1.07	$ .68
Difference – available for pipeline charges and cost savings to oil companies		$ .39

[1]U.S. flag ship operating costs are used (as contrasted to the foreign flag ship operating costs used elsewhere in this chapter) in accordance with the provisions of the Jones Act.

[2]The cargo loading and discharging rate for this smaller capacity pipeline was assumed to be slower than for the larger capacity pipeline previously discussed. Based on this assumption, it is estimated that it will take approximately 2 days at each end of the pipeline to moor the ship, discharge or load the cargo, and return to operating speed.

(2) If a pipeline is built and available for use when the sea-level canal is opened, it may be necessary for the sea-level canal to decrease tolls substantially over the life of the existing pipeline in order to attract traffic. The pipeline operating authority could decrease its prices to out-of-pocket costs including Panama tax. However, once the pipeline requires extensive capital replacements, it must charge prices near the level of existing Panama Canal tolls. Accordingly, for the long-term, the sea-level canal may be able to maintain tolls for crude oil at present Panama Canal levels or moderately lower.

(3) Were the requirement to develop for a huge continuing movement of crude oil permitting employment of ships too large to transit the sea-level canal in combination with the large capacity pipeline previously described, a substantial decrease in tolls might be required to attract such a movement. It is also possible that such a movement would not be attracted to a sea-level canal regardless of tolls levels.

The foregoing conclusions should be correlated with the previous analysis of alternative ship routing and ship size. Either in combination with a pipeline or independent of it, superships are quite competitive with a sea-level canal. Accordingly, tolls may need to be substantially lower per unit of cargo capacity for superships than for smaller ships.

Slurry Pipeline

The technology of moving solids by pipeline is now well established. Although currently only between 100 to 200 thousand ton/miles move annually by slurry pipeline, substantial growth of this method of transportation is expected in the future. Cargos for which slurry pipelines would be adaptable include coal, iron ore, potash, phosphate, copper ore and sulphur.

The slurry concept as adapted to the loading and discharge of bulk carriers enables these ships, formerly limited in maximum size due to the draft limitations of ports and the speed of shoreside cargo handling capabilities, to enjoy the advantages and economies now available to mammoth tankers. Slurried iron ore, coal and other bulk products can now be economically transported in giant OBO (ore/bulk/oil) carriers matching the physical size and ability of the largest tankers and able to transfer cargo by pumping through a submarine line while standing offshore.

The economics of operating a slurry pipeline are not significantly different from the economics of the petroleum pipeline previously discussed. Thus, for purpose of analysis, the cost presented for the petroleum pipeline can be used. The major difference between the petroleum pipeline and the slurry pipeline involves the required preparation of the cargo prior to movement through a pipeline. Quite obviously, utilization of a slurry pipeline requires that the solid material, iron ore, coal, etc., be ground into small particles which when mixed with water can be pumped through the pipeline. This grinding or preparation of the commodity may or may not represent an increase in the cost of transporting the product. For example, the iron ore mined in Peru is now ground, the impurities removed, and a pellet formed which has a much higher percentage content of iron ore oxide than the original ore prior to shipment. The ground iron ore rather than the pellet could be shipped by a bulk carrier to one side of the Isthmus, transported across the Isthmus by slurry pipeline, stored temporarily, and then loaded on another bulk carrier for transportation to its ultimate destination. At the destination the iron oxide could be pelletized for use in the blast furnaces. Thus, use of a slurry pipeline would only require a resequencing of when the pelletized operation occurs for the cargo. This resequencing of operations may not be without problems since there may be other factors influencing the decision to form the pellets in Peru rather than in the United States.

The major solid material now being transported through the Panama Canal is metalurgical coal originating on the U.S. East Coast and terminating in Japan. Inquiries were made regarding this cargo and it was reported that the slurry method would probably not be economically adaptable to metalurgical coal. Coal dust would not be usable in the

manufacture of high-grade steel and thus would require it to be formed into pellets at additional cost. Coal used as a source of energy, such as for the furnaces of an electric generating station, can be put in slurry form and utilized but no such coal currently transits the Panama Canal in large quantities.

The slurry pipeline does appear to offer a possible attractive alternative to the use of a canal. Its application would require a huge quantity of cargo, such as iron ore, to be economical. This again demonstrates that the economics of avoiding a canal are most attractive when there is one dominant movement of a commodity between a single source and a single destination. The presence of huge quantities permits an investment in facilities not justified with smaller quantities. The traffic forecast does not identify the commodities that will move through the canal in the future; thus, it is not possible to determine if a slurry pipeline would be practicable. However, the slurry pipeline does offer a potential to limit the ability of a canal to maintain current levels of tolls and almost certainly eliminates the possibility c. significantly increasing tolls on cargoes which could use a slurry pipeline.

Land Bridge and Railroads

The land bridge concept has received considerable exposure lately in various periodicals. It is a concept involving the combination of water transportation and railroad transportation to avoid the use of the Panama Canal. This concept has become feasible from an operating viewpoint because of the development of containerized traffic. Containers loaded with cargo at their origin can be transferred from one transportation mode to another expeditiously and at significantly lower cost than was previously possible.

As the term "land bridge" has gained popularity, the concept has been broadened in scope. Originally the land bridge concept was restricted to an international commerce route between the Far East and Europe moving overland via the North American continent by rail. However, the potential for increased rail tonnages has caused U.S. domestic carriers to broaden the concept to include traffic terminating or originating in the states which lie in the coastal areas opposite the foreign countries served. That is to say, the land bridge under the broadened concept has included goods moving both to and from the Far East and Eastern U.S. and between Europe and the West Coast, where both ocean and land transportation systems are employed.

The original interest in the land bridge developed with the closure of the Suez Canal in 1967 which required the diversion of Far East to Europe traffic from the formerly shorter Suez Canal route to the longer Panama Canal route. Advocates of the land bridge claimed that significant reductions in transportation miles and transit times could be achieved by the utilization of North American railroads rather than the all-sea route involving the use of the Panama Canal. Table V-10 presents a comparison of miles and transit time as between the land bridge route and the Panama Canal route for two combinations of traffic origin and destination: Yokohama – New York; and Yokohama – Europe. As is shown by Table V-10, there are significant savings in miles by the use of the land bridge route over the all-water Panama Canal route. However, for the Yokohama – Europe traffic, it is not possible to convert the mile savings to a saving in transit time because of the required transfer time between ships and railroads.

Advocates of the land bridge have analyzed international traffic in an attempt to identify cargos which can be containerized and thus constitute potential cargo for the land

TABLE V-10

PANAMA CANAL VS. LAND BRIDGE
COMPARISON OF NAUTICAL MILES AND TRANSIT TIMES

Route	Land Bridge Miles	Land Bridge Days	Panama Canal Miles	Panama Canal Days
Yokohama – New York[1,2]				
Yokohama – Los Angeles	4,800	9.0		
Los Angeles – New York rail	3,000	5.0		
Yokohama – New York			9,700	17.5
Canal delay time				1.0
Total	7,800	14.0	9,700	18.5
Yokohama – Europe[2]				
Yokohama – Los Angeles	4,800	9.0		
Transfer[3]		2.0		
Los Angeles – New York rail[4]	3,000	5.0		
Transfer[3]		2.0		
New York – Europe	3,700	7.0		
Yokohama – Europe			12,500	23.0
Canal delay time				1.0
Total	11,500	25.0	12,500	24.0

NOTES: [1]No provision made for port time since it is common to both routes.

[2]Sea time assumes 23 knot ship or 552 nautical miles per day.

[3]Assumes optimum situation of direct transfer between ship and an awaiting unit train.

[4]Transit time based on Atchison, Topeka and Santa Fe Railroad proposal.

bridge. Based on existing international traffic, the following is a summary of the long-tons of traffic now moving through the Panama Canal which advocates of the land bridge claim can be containerized:

Japan – East Coast U.S.	8,000,000 tons
Japan – Europe	1,000,000 tons
U.S. East Coast – Japan	1,000,000 tons
Europe – Japan	500,000 tons
Europe – West Coast U.S.	1,000,000 tons

By far the most significant quantity involves Japanese exports of manufactured products to the East Coast of the United States. Based on detailed records maintained by the Panama Canal Company, approximately one-half of Japanese exports of manufactured products to the East Coast of the United States involves manufactures of iron and steel. There is reason to doubt that this is cargo that is readily adaptable in an economic sense to containerization.

U.S. railroads have been keenly interested in the land bridge as a new source of traffic. Among the leaders of U.S. railroads in this matter has been the Atchison, Topeka & Santa Fe Railroad (ATSF). The ATSF has prepared a proposal of rail rates for the utilization of unit trains for land bridge traffic. These proposed rates are presented in Table V-11. The significant number on the table is the total one-way cost for one 20′ container of \$250. Present U.S. transcontinental freight rates for a similar 20′ container would be approximately \$400. (There are, of course, a variety of rates but \$400 is considered to be

TABLE V-11

LAND BRIDGE PROPOSED RAIL RATES BY ATSF RAILROAD

Unit Train Specifications	
Number of cars per train	80
Container capacity per train	320/20′
Minimum annual round trips	25
Trip days for one-way	5
Total Train Costs	
Cost per round trip without cars	\$144,000
Charge for cars per round trip	16,000
Total per round trip	\$160,000
Transportation Cost Per Container[2]	
Total cost one-way	\$ 250
Per container mile	\$.063
Per ton mile[1]	8.3 mils

NOTES: [1]Assumes average of 10 long tons per container.

[2]Assumes 100% utilization of unit train.

representative.) The significant point is that the ATSF has proposed to make a substantial freight rate reduction in an attempt to attract this new traffic. However, in doing so, they have assumed the possible risk of domestic shippers requesting similar rates.

The land bridge will need to compete with the all-sea route utilizing container ships. The new modern container ships which are currently being built have speeds in the range of 22 to 30 knots. The economics of container ships are summarized in Table V-12 for a 23 knot container ship with a capacity for 1,500 20′ containers. It should be noted that at optimum utilization the per ton mile cost for the container ship is 1.2 miles as compared with the optimum utilization cost of the proposed ATSF unit train of 8.3 mils.

TABLE V-12

ESTIMATED COST BY CONTAINERSHIP FOR THE TRANSPORTATION OF CONTAINERS BY FOREIGN FLAG OPERATOR

Ship Specifications	
DWT	26,000
Container capacity	1,500/20′
Service speed in knots	23
Daily fuel consumption in tons	250
Construction cost	$15,000,000
Panama Canal laden tolls	$15,000
Daily Operating Costs	
Capital recover[1]	$5,200
Hull and machinery insurance	190
Labor, maintenance & other expenses	1,200
Cost in port	$6,590
Bunkers (fuel)	3,190
Cost at sea	$9,780
Transportation Cost Per Container[3]	
Per day in port	$4.39
Per day at sea	$6.52
Per sea mile	$.012
Per ton mile[2]	1.2 mils

NOTES: [1]Assumes 340 operating days annually at 10% cost of capital over 20 years. Operating days include both days at sea and cargo loading/discharge time.

[2]Average of 10 long tons per container.

[3]Assumes 100% utilization of ship.

A series of tables has been prepared comparing the economics of the land bridge route with the all-water route. The first comparison is made in Table V-13 which compares the all-water route with the original concept of the land bridge route for Far Eastern traffic to Europe. Specifically, the table compares traffic originating in Yokohama, Japan destined for Europe. For such traffic the cost of the land bridge for one 20′ container is estimated to be approximately $432 versus the all-sea Panama Canal route cost of $166.48 or net difference $265.40. Note that the all-sea cost from origin to destination is less than the proposed ATSF rates for the land bridge section of the route alone. The comparison assumes optimum utilization of both the ship and of the unit train. However, even if the ship has a 50% utilization as compared with the optimum utilization of a unit train, there is still a significant advantage to the all-sea route. Accordingly, from the viewpoint of transportation cost, there is little apparent opportunity for the land bridge to compete with the all-sea route for traffic between the Far East and Europe.

TABLE V-13

COMPARISON OF COSTS FOR LAND BRIDGE AND PANAMA CANAL ROUTES
YOKOHAMA – EUROPE
20′ CONTAINER

Land Bridge	
Yokohama – Los Angeles – 9 days @ $6.52	$ 58.68
Port transfer charge	30.00
Ship delay – 2 days @ $4.39[1]	8.78
Proposed ATSF rail charge	250.00
Port transfer charge	30.00
Ship delay – 2 days @ $4.39[1]	8.78
New York – Rotterdam – 7 days @ $6.52	45.64
Total cost per container	$431.88
All Sea Panama Canal Route	
Yokohama – Rotterdam – 24 days @ $6.52	$156.48
Panama Canal tolls	10.00
Total cost per container	$166.48
Difference – land bridge excess	$265.40

NOTES: In comparison with the direct sea route, ships will have port time at either end of the land bridge. An allowance of 2 days at each port to arrive, discharge cargo and depart was assumed.

As previously identified, the largest volume of containerizable traffic originates in Japan and terminates on the U.S. East Coast. Table V-14 presents a comparison of costs as between the land bridge and the all-sea Panama Canal route for this traffic. No ship port time and terminal costs are included in this comparison since both routings would incur similar costs. This table again demonstrates the substantial financial advantage of the all-sea Panama Canal route over the routing including the land bridge. Even if the ship discharging its cargo on the East Coast of the United States were required to return empty and U.S. railroads were willing to return the containers to the West Coast of the United States free of charge, the all-sea Panama Canal route would still have an advantage. Accordingly, significant increases in tolls charges against the ships using the Panama Canal could be made without diverting traffic through the canal to a land bridge route.

The traffic between the West Coast of the United States and Europe has not been analyzed to determine the cost differential between the land bridge route and the all-sea Panama Canal route. No analysis was considered necessary since the differential and conclusions would be comparable to that for the Far East to the East Coast of the United States, as described previously.

The final comparison between the use of U.S. railroads and the land bridge route with the all-sea Panama Canal route to East Coast U.S. ports is presented in Table V-15 for traffic between Asia and the U.S. Midwest. Specifically, the traffic analyzed is between Yokohama and Chicago. The degree of confidence in the findings of this comparison is considered to be very limited due to the absence of any known data on possible U.S. rail rates. For purposes of comparison it was assumed that U.S. railroads may be willing to offer freight rates

TABLE V-14

COMPARISON OF COSTS FOR LAND BRIDGE AND PANAMA CANAL ROUTES
YOKOHAMA – NEW YORK
20′ CONTAINER

Land Bridge	
Yokohama – Los Angeles – 9 days @ $6.52	$ 58.68
Los Angeles – New York rail	250.00
	$308.68
All Sea Panama Canal Route	
Yokohama – New York – 18.5 days @ $6.52	$120.62
Panama Canal tolls	10.00
	$130.62
Difference – land bridge excess	$178.06

between Los Angeles and Chicago at about 60% of the proposed ATSF transcontinental rate. By so doing the western railroads in the United States would be attempting to compete for traffic that is now held by the eastern roads. It is reasonable to assume that the eastern roads would respond by offering rate reductions in order to retain the traffic. It has been assumed that the minimum offering by these eastern roads would be approximately 40% of the proposed ATSF transcontinental rate. The assumed rail rates for the Los Angeles to Chicago route are unrealistically low in comparison to existing domestic freight rates. However, the western railroads may be willing to make substantial rate reductions in an attempt to attract this new source of international traffic. Under the assumptions made, the land bridge route does offer a slight advantage over the all-sea Panama Canal route. The significance of this result in terms of competition for a future canal is probably limited for the following reasons:

1. The assumed U.S. freight rates may not materialize.
2. The amount of traffic from Japan terminating in the U.S. Midwest is not substantial.

TABLE V-15

COMPARISON OF COSTS FOR LAND BRIDGE AND PANAMA CANAL ROUTES
YOKOHAMA – CHICAGO
20' CONTAINER

Land Bridge	
Yokohama – Los Angeles – 9 days @ $6.52	$ 58.68
Los Angeles – Chicago by rail[1]	150.00
	$208.68
All Sea Panama Canal Route	
Yokohama – New York – 18.5 days @ $6.52	$120.62
New York – Chicago by rail[2]	100.00
Panama Canal tolls	10.00
	$230.62
Difference – all-sea route excess	$ 21.94

NOTES: [1]Based on the ATSF proposal, the transcontinental rate is $250 – Assuming a 60-40 split over Chicago, the Los Angeles – Chicago rate would be $150.

[2]The New York – Chicago rail rate is unrealistically low based on present domestic rates. However, if the western railroads were to propose special rates to attract this traffic, it is reasonable to assume that the eastern roads would respond with competitive rates.

[3]No transfer and ship delay time are shown since they are common to both routes.

The foregoing analysis supports the conclusion that the land bridge and U.S. railroads do not appear to limit the potential for a canal to maintain present levels of tolls or to make significant increases in them. This may appear somewhat surprising since U.S. railroads have effectively competed for traffic formerly carried by ships between the two U.S. coasts utilizing the Panama Canal. However, the economics of traffic originating and terminating in the United States is significantly different from the economics of traffic which can use foreign flag ships. In the case of U.S. traffic, the Jones Act requires that the cargo be carried on ships both built in the United States and operated under the U.S. flag. These ships have a level of cost at least double that of foreign constructed and foreign flag operated ships.

Aircraft

The transportation by air of high value to weight cargos will continue to show significant growth. Supersize jumbo jets and air busses are expected to expand the range of commodities which are not subject to air freight competition. Table V-16 summarizes forecasts of free world air freight from 1970 to 1980 made by various U.S. corporations. These forecasts demonstrate the anticipated impressive increases in the quantity of cargos moving by air.

Although air freight has grown substantially in recent years and is anticipated to continue its growth rate, the aggregate quantity of cargo moving by air remains insignificant in comparison to total world cargo movements. Assuming the forecast volumes of traffic materialize, air freight will still account for less than 1% of the aggregate ton/miles of cargo moved in 1980.

The comparison of the cargo capacity of the largest aircraft with existing ships will assist in understanding the significance of air freight as a source of competition for a

TABLE V-16

FORECAST OF FREE WORLD AIR FREIGHT
As Prepared by Various U.S. Companies

Company	Year Revised	Forecast Billions of Ton/Miles		
		1970	1975	1980
Boeing	1969	10	24	45
Douglas	1968	9	27	78
General Electric	1968	11	27	53
Lockheed	1966	12	26	55
Pratt & Whitney	1968	10	25	55
Sperry Rand	1967	11	29	--

sea-level canal. The largest existing aircraft for the carriage of cargo is the U.S. Air Force C-5A for which the Lockheed Aircraft Company has a planned civilian version referred to as the L-500. The L-500 has a maximum gross payload of approximately 145 long tons. Gross payload is used since it is comparable to the cargo deadweight of ships. It is estimated that the L-500 has an annual ton/mile productivity of approximately 237 million. The container ship referred to in Table V-12 would be utilized to carry comparable cargos. Assuming a cargo capacity of 20,000 long tons for the ship and further assuming 200 operating days at sea per year, the ship would have an annual productivity of 2.2 billion ton/miles. Thus, it would require nine L-500's to match the annual ton/mile capacity of one container ship. The original construction cost of a container ship is approximately $15,000,000 whereas the estimated cost of nine L-500's is $207,000,000.

Although aircraft may compete in a limited manner for high-value manufactured products, it is currently inconceivable that they will be used for bulk commodities. One simple illustration assists in placing this in perspective. Two 300,000 DWT ships have the capacity to carry the entire free world projection of air cargo traffic for the year 1980.

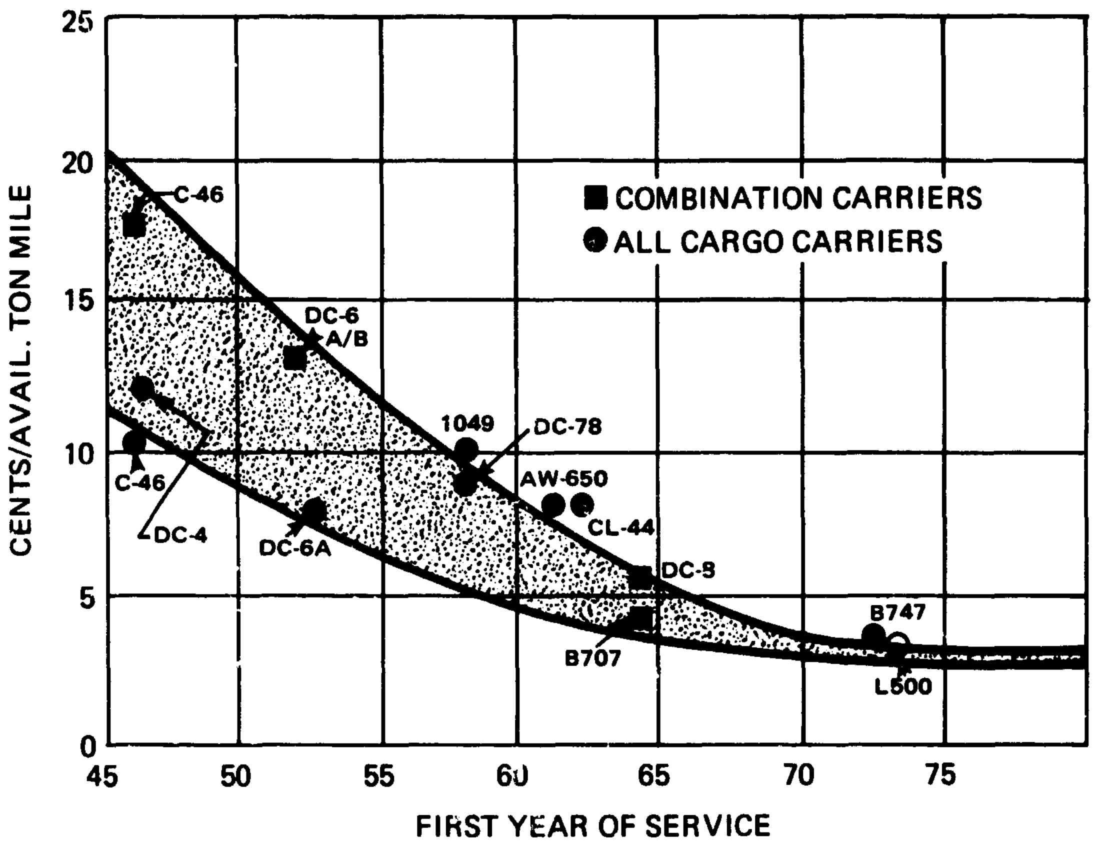
There is a wide difference in operating costs as between container ships and aircraft. As previously presented in Table V-12, the per ton mile cost of the container ship is between 1 and 2 mils. The optimum level of operating cost for an L-500 is between 3.0 to 5.0 cents per ton/mile. The existing and planned container ships can grow substantially in size while decreasing their cost per ton/mile by taking advantage of the economies of scale for water transportation. However, based on present technology, it appears that the aircraft are near the bottom of the economies of scale curve. Figure V-4 presents a history of aircraft direct operating costs. There is no detailed information available on the cost of aircraft larger than the Lockheed L-500 or the Boeing 747, but aircraft manufacturers have indicated that larger aircraft will not produce significant cost savings.

If aircraft are to divert sufficient cargoes from ships to affect future canal traffic significantly, it will be necessary for them to carry such cargoes as automobiles. Cargoes currently carried by aircraft are of such high dollar value and move in such special circumstances that were aircraft to carry all such cargoes currently using the Panama Canal there would be no noticeable effect on canal traffic. A forecast of air cargo by trade area is presented in Figure V-5. It should be noted that the two major routes involve U.S. domestic and North Atlantic traffic. The possible routes which could affect canal traffic are not large.

To overcome the significant disadvantage in terms of transportation cost, aircraft must look to other factors influencing cost which are favorable to their type of service. For example, shippers of highly perishable products such as flowers and fruits and very high-dollar value cargos are willing to pay the substantially higher air freight rates. There has been discussion that cargos such as automobiles may have cost factors other than transportation which result in air transportation being in a competitive position. To evaluate this possibility, transportation cost data have been obtained for automobiles originating in Japan and terminating in Chicago and are presented in Table V-17.

The data presented in Table V-17 were estimated in the following manner:

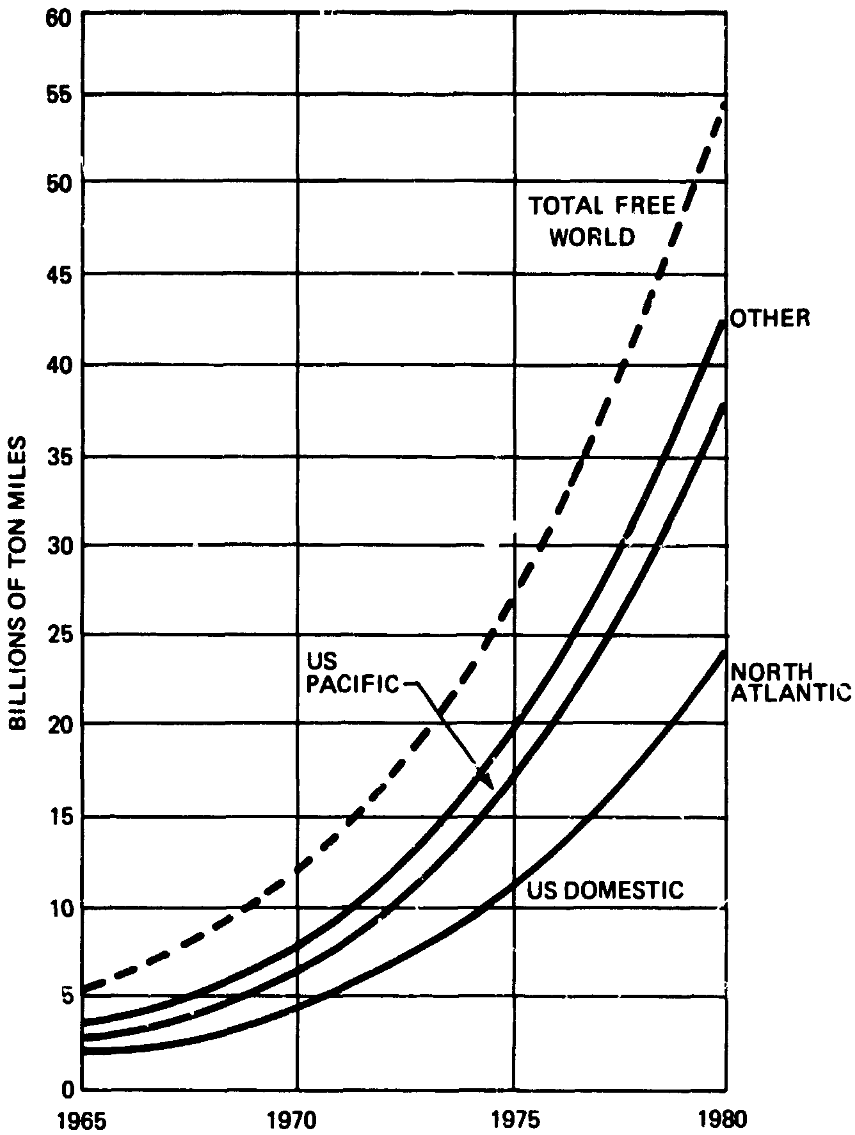
1. The transportation cost by ship of $120.00 is based on the 1.2 miles per ton/mile for a containership as presented in Table V-12. This tends to overstate the cost since a high speed type containership would probably not be used to transport automobiles.



From New Dimensions in Air Commerce
Lockheed Georgia Company

HISTORICAL TON MILE COSTS (U.S. OPERATORS DIRECT COSTS)

FIGURE V-4



From New Dimensions in Air Commerce
Lockheed Georgia Company

FREE WORLD AIR CARGO BY TRADE AREA

FIGURE V-5

TABLE V-17

COMPARISON OF OCEAN AND AIR SHIPMENT COSTS
AUTOMOBILES FROM YOKOHAMA TO CHICAGO

Cost Item	Cost Per Automobile	
	Ocean Shipping	Super Aircraft
Transportation costs		
Preparation for transport	$ 10	$
Delivery to major transport	(1)	(1)
Major transportation		
Loading	(2)	(2)
Shipping cost	120	420
Unloading	9	(2)
Insurance	15	2
Damage and pilferage	10	–
	$164	$422
Delivery to distributor warehouse	12	
Delivery to dealer	50	12
Total transportation	$226	$434
Possession costs		
Storage at warehouse	26	
Warehouse inventory carrying cost	26	
In-transit inventory carrying cost	15	2
Total possession costs	$ 67	$ 2
Service costs		
Lost sales		
Manufacturer	$ 16	–
Dealer	32	–
Total service costs	48	–
Total cost of distribution	$341	$436

NOTES:

[1] Assumed same for both.

[2] Included in shipping cost.

2. The shipping cost by super-aircraft is based on a cost per statute mile of $7.00 for an L-500 with a capacity to carry 106 automobiles. In a similar manner to the ship, it was assumed that the aircraft would have a backhaul cargo.

3. The remaining costs were obtained from the Lockheed-Georgia Company, in an pamphlet entitled "Distribution of Imported Cars." It is difficult to estimate many of these costs or to evaluate the estimates that have been made but since they have been prepared by a manufacturer of super-aircraft, it was assumed that they were not unreasonably low. Based on the assumptions made, it should be noted that the cost by super-aircraft is significantly higher than by ship.

For the purposes of evaluating the potential diversion of traffic from a canal to aircraft, Table V-18 presents a description of cargos with a value between $1,000 – $2,000 per long ton and over $2,000 per long ton. These cargoes were selected as being of such a value as to represent potential cargo for aircraft. The two major commodities are automobiles, previously evaluated, and small shipments. The total traffic shown in Table V-18 represented 4% of FY 1967 commodities transiting the Panama Canal. The carrying cost of inventory with a cost of $2,000 a ton using a cost of capital of 10% is approximately $17 per month. Obviously, cost factors in addition to high value and reduced in-transit time for a cargo must be present to overcome the substantial cost differential between air and ship freight.

Based on the foregoing presentation, it is concluded that although air freight will experience considerable growth in the future it is not a significant limiting factor on the ability of a canal to either maintain the present level of tolls or to increase tolls substantially.

Non-transportation Alternatives

The foregoing discussion evaluated the transportation alternatives for the commodities that could use a sea-level canal. Other than transportation alternatives, there are available the following possibilities which could limit the use of a canal: (1) alternate sources and markets, (2) alternate shipping services, (3) alternate resource development.

It is a conclusion of the study that alternate transportation is the most reliable measure of the sensitivity of a sea-level canal to tolls. However, it is recognized that other alternatives cannot be ignored. The principal obstacle to their evaluation is that they are difficult, if not impossible, to quantify other than on a purely judgmental basis.

The only evaluation available on these other alternatives was made by SRI in its 1967 study for the Panama Canal Company. SRI concluded that such alternatives would permit the Panama Canal to increase tolls in a range of 100 to 150 percent to maximize its revenue, except for the following commodities:

1. Bananas – It was concluded that this commodity is very sensitive to tolls increases because alternative sources are available or could be readily developed on the Caribbean side of the canal.

2. Bauxite and alumina – It was concluded that bauxite and alumina are limited to tolls increases of 50% because of the alternative sources in the Pacific basin.

3. Scrap metal – It was concluded that scrap metal was very sensitive to tolls increases because of alternative sources as well as the use of pig iron as a substitute.

4. Sulphur – It was concluded that sulphur is limited to tolls increases of 50% because of alternative sources.

TABLE V-18

HIGH VALUE/TON COMMODITIES USING PANAMA CANAL FY 1967

(000 Long Tons of Cargo)

$1,000 – $2,000/Ton

Commodity	Long Tons
Food	
Meat preparations	26
Butter fat	27
	53
Tobacco	77
Crude materials	
Wool	219
Synthetic fibers	28
Other	1
	248
Manufactured goods by material	
Articles of rubber	34
Special fabrics	25
Articles of textiles	23
Copper metal	137
Tools	20
Other	31
	270
Machinery & transport equipment	
Agriculture machines	91
Metal working machines	96
Electric distribution equipment	48
Passenger cars	345
Trucks	70
Vehicle parts	165
Other	22
	837
Misc. manufactured articles	
Furniture	23
Other	45
	68
	1,553

Over $2,000/Ton

Commodity	Long Tons
Uranium	2
Chemicals	
Medicinal products	26
Explosives	60
Other	14
	100
Manufactured goods by material	
Textile yarn	24
Cotton fabrics	102
Other fabrics	21
Carpets	37
Metal containers	25
Other	29
	238
Machinery & transport equipment	
Power machines	58
Textile machines	31
Special industrial machines	90
Machines, not classified	276
Communication equip.	38
Electric-machines, not classified	78
Other	38
	609
Misc. manufactured articles	
Clothing	47
Footwear	46
Toys	72
Other	74
	239
Cargo unclassified of individual shipments less than 5 tons each	1,026
	2,214

Those commodities identified as being sensitive to other than transportation alternatives constitute a minor percentage of the total traffic of the existing Panama Canal. In addition, evaluation of non-transportation alternatives presents such difficulties in measurement as to place serious question as to its validity. As an example of the difficulty in evaluating such alternatives, the matter of alternative resource development can be briefly examined. Most commodities are available in many places in the world, and their movements over the long term can be expected to be selective, based on the least cost alternatives. In selecting which development is to occur, such matters as the existence of inland transportation systems, the distance between the source and water transportation, and the politics and the tax laws of the host country need to be considered. The importance of these matters in terms of cost and risk are so overwhelming as to make the matter of canal tolls almost insignificant. Canal tolls could only be the determining factor in that theoretical instance in which the conditions of two developments were approximately equal.

For the aforementioned reasons, it has been concluded that non-transportation alternatives cannot be evaluated as a limiting factor for a sea-level canal to collect tolls at some future date.

Availability of Alternatives Varies Over Time

In the short-term there is little that shippers and ship operators can do in response to a tolls increase. This is because they are committed to existing ships, schedules, routes, location of resources, and other factors. However, in the long term all the alternatives to the use of the canal become available. For example, larger and additional numbers of ships can be built, new contracts arranged, alternate resources developed, and other arrangements made. The important consideration in the evaluation of a sea-level canal is the long-term effect.

There can be short-term responses to tolls that vary significantly from long-term responses. This is because in the short term, decisions are often made based on the out-of-pocket effects on costs and revenues rather than the long-term effect. There are two types of short-term responses as follows:

1. Out-of-pocket Costs: If a ship owner has an excess of ships available at a particular moment, he may evaluate the use of a canal based on his out-of-pocket costs. The out-of-pocket costs of operating a ship may only be its fuel because even labor costs are sometimes fixed by long-term contract.

2. Opportunity Costs: If a ship owner is temporarily short of ships and has the opportunity for additional revenue, he may be willing to pay substantially higher tolls for the purpose of saving time.

Neither the out-of-pocket nor the opportunity cost comparisons are relevant to an evaluation of the long-range potential of tolls for a sea-level canal. Short-range considerations may have an effect for short periods, but they are impossible to forecast over a long period.

Tolls Structure

Synopsis

The matter of a tolls structure is essentially the question of "Who pays?" with consideration also given to "Why?" This section of the report will examine factors which

will be relevant to a sea-level canal in selecting an appropriate system of tolls assessment for the purpose of obtaining the required level of revenues to cover its costs.

There are, of course, two viewpoints regarding a tolls structure: (1) the financial effect on a sea-level canal, and (2) financial effect on the users. It is intended that only the former problem will be evaluated. However, recognition will be given to the need for evaluating the latter before a change is made.

There is a traditional method of assessing ships for the use of ship facilities which includes the existing Panama Canal tolls system. The adoption of this traditional approach would have the advantage of being well known and accepted and thus perhaps subject to the least amount of controversy. The traditional method has applicability for a sea-level canal if tolls rates remain substantially the same as present Panama Canal rates. However, as discussed previously, even at present rates some differentiation of tolls charges may be necessary to retain traffic that moves in huge quantities.

If it is decided that an increase in the level of tolls is necessary, then consideration of an alternate system of tolls is particularly appropriate. The previous part of this Chapter described how tolls that a user is willing to pay cannot be greater than the benefit accruing to it by the use of the canal. As tolls are increased, it is necessary for a tolls system to identify with greater precision the extent of the benefit to each class of user. The absolute maximum revenue could theoretically be obtained from a system that collected from each user a different toll based on its benefit in using the canal. Such a system can exist in theory only since it would be impractical to administer. The maximum tolls system in terms of revenue production is one that would most accurately identify the benefits to all users while being practical to administer. Consideration also needs to be given to the marginal direct cost of rendering the services since this should establish the minimum level for a tolls charge.

The administration of a sea-level canal may be required to obtain a higher level of tolls or to respond to new technology which is effectively competing for traffic. A pricing structure which would provide the necessary flexibility so that traffic could be retained is a marginal cost pricing system. Using such a system the administration could set rates not higher than the value of service and not lower than the direct marginal cost of providing service. If permitted to use such a pricing structure, this would provide the greatest assurance for the financial success of a sea-level canal.

The Tonnage Principle

Ships are universally assigned values referred to as "tonnage" which is expressed as both a gross and net quantity. Theoretically, the gross tonnage represents the cubic size of a ship from which are deducted spaces dedicated to the propulsion of a ship to arrive at net tonnage. The principal deductions include spaces dedicated for the engine and related fuel facilities, crew quarters and safety equipment. Each ton is equivalent to 100 cubic feet. Thus, when a ship is referred to as being 50,000 net registered tons the expression has nothing to do with weight but rather only with the ruler.

The principles underlying tonnage were first promulgated by the Englishman George Moorsom in 1854. Although these principles are universally accepted, their application because of the adoption of unique measurement rules varies considerably from country to

country and between the Panama and Suez Canals. This variation requires each ship to maintain separate certificates of measurement for the Panama and Suez Canals in addition to its national tonnage. The national tonnage, also referred to as registered tonnage, is determined under the measurement rules of the country where the ship is registered and whose flag it flies.

A ship's national tonnage is generally used for the application of safety rules and the assessment of charges against ships including such items as registration taxes, port charges, tug services, and pilotage. Both gross and net tonnage are used as a basis for these charges with little consistency among the countries of the world. In addition, both the Panama and Suez Canals charge ships based on tonnage developed under their own rules.

Tonnage As An Economic Value

The determination of ship tonnage is normally the province of naval architects in that it is based on the engineering features of ships. Although the principles of ship tonnage are very easily described and understood, the actual application of rules of measurement represents a fairly substantial undertaking involving interpretation of numerous rules and regulations. In its most basic form, ship tonnage is nothing more than taking a ruler and measuring the internal cube of a ship.

Although it is usually thought of as a matter pertaining to physical characteristics, tonnage is of primary economic importance. The tonnage values assigned ships are used as a basis for distributing the costs of maintaining ship facilities of the world. Tonnage provides an answer to the question of how to distribute the burden of costs among the users of the facilities. As such, it represents an economic value of primary importance to ship owners.

Panama Canal System

The present method of tolls assessment for the Panama Canal was placed in effect at the time of its opening in 1914 and was developed by studies completed in 1913 by Emery R. Johnson, Special Commissioner on Panama Canal Traffic and Tolls. Both the system and rate of tolls placed in effect at the opening of the canal have remained basically unchanged. As described in Chapter II, the current rate for commercial ships is 90¢ a net ton for laden ships and 72¢ a ton for ships in ballast, i.e., empty.

Both the method of tolls assessment and the level of rates for the Panama Canal are established by statute. Regarding rates the statute provides that the rates be established at a level to recover specific costs. Such costs include all costs of operating the Panama Canal, interest on the U.S. investment at the current average cost to the U.S. Treasury of its bonds outstanding, and depreciation. However, no depreciation provision is made for the costs incurred in excavating the original channels and harbors. The law limits rates so that they can neither be higher nor lower than needed to recover the specified costs.

Emery R. Johnson, in his work for the Panama Canal, concluded that it needed its own set of tonnage rules for the following reasons: (1) the national rules of tonnage measurement were not uniform, and (2) the Suez Canal system was not as perfect as Johnson would have liked it to be. The Panama Canal has maintained its own set of

measurement rules from the outset of its existence to assure equal treatment of like ships which transit the Panama Canal.

Universal Tonnage System

The existence of various rules of measurement by the canals and nations of the world, although all applying the same principle, has always been a source of concern to the maritime nations and industry. For example, the United Kingdom's Board of Trade in 1862 took a position strongly favoring a universal system. Emery R. Johnson in his work for the Panama Canal hoped that the Suez and Panama Canal rules would be unified to provide a basis for a universal system. After World War II the continental European countries developed a new system referred to as the Oslo Rules and hoped that this would provide a basis for a universal system. In the past all these attempts have met with failure.

In 1960 the Inter-Governmental Maritime Consultative Organization (IMCO), an agency of the United Nations, started work on a universal system. A subcommittee of IMCO worked for nine years considering various proposals. Although there was general recognition regarding the desirability of one system, various interests urged that such a universal system incorporate features of particular advantage to them. This entire effort culminated with the International Tonnage Conference, 1969, which was convened in London. After approximately one month's work this conference, which included representatives of all the principal maritime nations of the world, proposed a universal system. The successful implementation of this proposed system requires acceptance by nations representing at least two thirds of the world's existing ship tonnage through their usual governmental action. In the case of the U.S. this would require a two-third's vote of the U.S. Senate since this represents an international treaty.

If the Panama Canal were to adopt the universal system, it would not represent a major change in its basis for assessing tolls but a continuation of the traditional approach.

The Effect of the Panama Canal System

As previously described, the present Panama Canal tolls system assesses ships based on their internal cubic capacity. Generally, this has a close approximation to the cubic capacity of the ship for carrying cargo. The closest approximation is achieved for tankers. An example of a ship type where the system does not produce a close approximation is container ships. The unused spaces among the containers and between the containers and the hull are included in net tonnage. However, container ships usually carry significant amounts of containers on deck and these are excluded from net tonnage under the theory that they are not part of the ship.

Although the present system assesses charges only against ships, such charges can be related to the ship's laden cargo. The correlation is, of course, obvious when a ship is only carrying one cargo but becomes difficult to estimate for general cargo ships carrying hundreds of different cargos.

Although the present tolls rate for laden ships is a uniform 90¢ per cubic ton, the resultant effective charge per long ton of cargo varies considerably because of the varying density of different commodities as illustrated by the following table which assumes no ballast return:

Commodity	Toll Per Panama Canal Ton	Average Weight Tons Per Cubic Ton	Calculated Effective Toll Per Long Ton
Iron ore	$.90	6.7	$ .14
Coal	.90	2.4	.38
Fuel oil	.90	2.6	.35
Corn	.90	2.0	.45
Automobiles	.90	.1	9.00

The weight tons per cubic ton used in this illustration are based on the average physical characteristics of the commodity.

There are, of course, many additional factors which influence the effective tolls rates by commodity . An obvious factor is the degree to which a ship is fully laden. If a ship is only laden to the extent of one half of its capacity, obviously the effective tolls rate will be twice what it would have been had the ship been laden to capacity, since the present tolls system assesses tolls based on capacity and not cargo actually carried. Similarly, if a ship regularly transits laden and must return in ballast, the effective toll rate per long ton is almost twice that of a ship that has a backhaul cargo. Return ballast transits are common for tankers.

Another factor which is not quite so obvious is the effect of ship type on cargo carried due to ship design. For example, an ore carrier is especially designed for iron ore and has only the small cubic capacity required to carry the heavy iron ore. Conversely, the bulk carrier has twice the cubic capacity, permitting it to also carry more bulky but less heavy cargos such as coal and grains. Since a ship is assessed on cubic capacity, the bulk carrier is charged twice the amount of tolls per weight ton of capacity.

The present system, because of the factors described above and due to other factors, has the effect of producing a range of tolls rates by commodity. The table below illustrates the average and range of effective tolls rates for typical commodities using the Panama Canal based on studies made by the Panama Canal Company:

	Tolls Per Long Ton		
Commodity	Lowest	Highest	Average
Manufactured steel	$ .20	$ .70	$ .46
Coal	.45	.90	.55
Rice	.45	1.50	.65
Soybeans	.70	1.75	1.09
Paper	.70	3.00	1.53
Bananas	1.50	4.00	2.76
Automobiles	2.00	13.00	7.23

Pricing Based on Cost

However structured, the rates must produce sufficient aggregate revenue to cover all costs. The problem is how to best structure the rates to obtain the necessary revenues.

Possibly the most obvious basis for structuring rates, and the one which may appear to be most fair, would be to refer to the cost of rendering the service. As an example of such a pricing system reference can be made to the merchandise industry. If a customer spends $1.00 for a grocery item at the supermarket, it is likely that 70¢ or more represents the out-of-pocket cost of the item to the supermarket. Prices for which cost represents a high percentage of the total are characterized as being based on "cost of service."

It is important to note that the relevant costs in a pricing decision are direct costs or those that can be identified with the service rendered. The purchase cost of the item to the supermarket is a direct cost and relevant to the pricing decision. In contrast, take the example of a theater. The cost of producing a play cannot be identified with any one seat or group of seats within the theater. Of course, various assumptions can be made on how to relate such costs but these assumptions are arbitrary.

The construction cost of building a sea-level canal should be examined to determine if it forms a basis for pricing. The most obvious possibility would be the cost incurred to render transit service to large ships if conventional excavation methods are used. The incremental construction costs to provide transit service for ships, say, above 100,000 DWT, should be recovered from these ships or from an economic viewpoint such additional costs should not be incurred. To the extent that such costs are unrecovered from the users for which the costs were incurred the remaining users are required to pay this deficiency.

Other than construction costs, the other source of cost data for a pricing decision for a sea-level canal would be the operating costs. Those operating costs which directly relate to a particular type of service or type of ship should be assessed to the user receiving the service. The existing Panama Canal has only a small percentage of operating costs which can be so related. It is likely that a sea-level canal would, if anything, have a lower percentage.

It is probable that cost data will provide little basis for structuring tolls for a sea-level canal. Although incremental construction costs should provide a guide based on projections of large ship use of the sea-level canal, there is probably little likelihood that these users would be willing to pay the resultant heavy tolls charges. The fact that such large ships should pay a substantially higher toll is academic if the value of service rendered (such as the cost to the ship of taking an alternative route) is less.

Pricing Based on Value of Service

The value of the service rendered establishes the ceiling on prices. If a proposed toll charge exceeds such value, the commodity and ship will cease to use the sea-level canal.

Differentiating prices on the basis of the value of service received can be justified. Commodities and ships with little opportunity to divert from the sea-level canal can be charged much higher tolls since the value of service received is also high. Conversely, traffic with economic alternatives to the use of the canal are receiving a lesser benefit or value of service and thus the toll charge should be lower. A previous part of this Chapter discussed in detail the measurement of value of service based on such alternatives as ship routing, ship size and pipelines.

There is often a misunderstanding of the difference between a toll based on value of service and value of cargo. *Ad valorem* is another description for a value of cargo basis. The fact that cargo has high value may justify higher tolls based on such standards as fairness but this does not mean that the cargo is more limited in its alternatives to the use of a sea-level canal. Shippers of low value phosphate rock may have limited opportunity to divert from the canal and thus would be willing to pay substantially higher tolls than would be shippers of higher value bananas with several alternatives available.

Marginal Pricing

Previous sections of this report discussed cost of service and value of service as a basis for pricing. This section will combine the two concepts into what is referred to as marginal pricing.

Each ship transiting the canal should pay as a minimum an amount equal to the direct costs of rendering service. In addition, each transit should make a contribution toward the fixed operating and sunk investment costs of the canal. The total charge cannot exceed the value of service (benefit received) or the demand for the service will disappear. Such a concept is referred to as marginal pricing.

A business or financial undertaking with a high level of sunk investment and/or fixed operating costs is one in which the marginal pricing concept is most applicable. These, of course, are the cost characteristics of the sea-level canal. The following data are assumed to illustrate the concept.

Traffic Analysis

		Present Tolls	
Ship Type	Total Transits	Per-transit	Total
Small	1,000	$ 600	$600,000
Large	100	2,000	200,000
		Total Revenue	$800,000

Regarding the opportunity to increase tolls, assume that 100 of the small ship transits and 20 of the large ships would not be willing to pay any additional tolls; i.e., a tolls increase would result in a loss of the traffic. Further, assume that increases of 100% can be made on the remaining traffic or 900 of the small ships and 80 of the large ships.

Total Annual Canal Costs

Fixed costs –	
Interest	$550,000
Investment recovery	100,000
Fixed operating	70,000
	$720,000
Marginal costs –	
Small ships ($50 transit)	$ 50,000
Large ships ($300 transit)	30,000
	$ 80,000
Total Costs	$800,000

Assume that a 25% increase in revenue is required to meet expected increased costs or a revenue objective of $200,000 after all present expenses. Further, assume that as a matter of equity an across-the-board increase is made. This would result in the loss of 100 ($60,000) small ship transits and 20 ($40,000) large ship transits that were sensitive to any tolls increase, a total of $100,000 of revenue before the increase, less $11,000 in marginal costs, or a net loss of $89,000. To make up for this loss in traffic and produce a net increase in revenue of 25% would require that the remaining transits must absorb an additional increase in tolls. The less sensitive traffic would thus have their tolls increased a total of $289,000 or 41%.

Assume that rather than an across-the-board increase a selective rise is made based on traffic sensitivity. The sensitive traffic is assigned no increase and the entire additional $200,000 is absorbed by the less sensitive traffic. This results in a 29% increase to the less sensitive traffic.

The foregoing example indicates that if a canal is in competition with alternatives, has a high level of sunk and fixed operating costs, and low marginal costs, a marginal pricing system is beneficial both to the canal and users. So long as any traffic is covering more than its marginal costs, there is no financial justification to take action which results in losing such traffic. In fact, a canal should attempt to attract all possible traffic willing to pay tolls that exceed to any extent the marginal cost of providing service.

Although marginal pricing may be unique in the maritime industry, it is commonplace both in other forms of transportation and in other industries. An outstanding example of the application of the marginal pricing concept is the substantially lower evening and weekend telephone long-distance rates charged by the Bell Telephone System.

The essential but difficult determination under a marginal pricing system is the determination of value of service. This may be best measured by commodity, ship route, a combination of both, ship size, or possibly some other basis. The selection of a parameter should be made on the basis of the one that most accurately measures value of service and provides a system that is practical to administer. To a substantial degree, value of service measurement requires the application of judgment. Admittedly, it may be difficult to make

these judgments, but such difficulties should not preclude the application of sound principles.

It should be recognized that opposition to a marginal pricing system could develop. The basis for such opposition could be based on the discriminatory aspects as well as the difficulty in measuring value of service previously discussed. Arguments of discrimination will be put forth by those interests which must pay the higher rates. Depending on the type of canal administration that has been established, the political pressures brought to bear on behalf of various interests for lower rates may be difficult to treat. In the case of telephone prices previously cited, there has been little difficulty justifying them because the reductions went to the "right" groups; i.e., the general public receives the lower rate rather than the businessman.

At existing levels of tolls the traditional tolls structure as represented by the Panama Canal or proposed universal tonnage system may be appropriate. However, even at existing levels of tolls some differentiation in charges may be necessary for traffic that can use huge ships. If additional levels of revenue are necessary, it is fairly certain that a different tolls system will be required to retain the traffic, and the system that is most likely to assure the financial success of the sea-level canal would be marginal pricing. By such a system the canal administration would have a vehicle by which to respond to competition as it developed from such sources as new technology. With its low level of marginal costs, there is little traffic from which the canal would not financially benefit by attracting.

Administrative Feasibility

In designing a tolls structure, simplicity and acceptability are desirable attributes. Rate structures should be easy to understand and enable the canal administration to administer them currently and impartially. In this regard, it is desirable to minimize the number of rate elements and to select rate elements which identify meaningful service features.

Traditional tonnage systems have a long history of acceptability and are reasonably easy to administer. Undoubtedly, a marginal pricing system would be more difficult but such a system could be administered on a reasonable basis if the number of commodity or other classifications were limited. The number of classifications required should be determined at the time of a decision to implement a marginal pricing system. If some large user such as crude oil could be lost to an alternate, possibly only two rates of toll would be required: one for crude oil, and a second for all other traffic.

It should be possible to construct a tolls structure based on the principles of marginal pricing that is administratively feasible. In support of this conclusion, it may be desirable to illustrate the type of structure that is contemplated. The basic charge against the ship would be set at a level to recover from each transiting ship the marginal cost of providing transit service. The traditional ship tonnage basis could possibly be used for this purpose. The second component of the toll would be a charge of varying rates depending on the alternatives of that commodity or ship to the use of that canal. Assuming that commodity would be the most appropriate measure of the value of the service, Table V-19 illustrates the type of commodity classification that may be established. In an attempt to indicate the degree of administrative difficulty associated with this type of tolls structure, Table V-19 indicates for Fiscal Year 1967 the percent of the commodity classification which transited the canal on ships carrying only that single commodity. It should be noted that for most

TABLE V-19

SUMMARY OF MAJOR COMMODITY MOVEMENTS
THROUGH PANAMA CANAL
FISCAL YEAR 1967
(000 Long Tons)

Commodity	Long Tons Total	Long Tons Percent Single Commodity Ship[1]
Crude Oil	5.3	88%
Petroleum Products	11.5	89
Coal	9.4	93
Iron Ore	4.0	99
Sugar	3.3	99
Bananas	1.4	88
Coarse grain	3.9	76
Soybeans	2.0	55
Lumber	4.4	77
Alumina/Bauxite	1.3	97
Phosphate Rock	3.6	78
Wheat	1.7	82
Scrap Metal	3.5	99
Rice	0.6	81
Wood Pulp and Paper	1.8	33
Nitrogenous Products	2.6	65
Sulfur	0.8	68
Chemicals	1.7	34
Manufactures of Iron and Steel	5.3	51
Motor Vehicles	0.6	38
Non-ferrous Ores	1.0	46
All Others	16.5	–
	86.2	

Note: [1]Percent of total long tons of commodity classification transiting the Panama Canal in ships which are laden with that single commodity.

commodity classifications the preponderance of the tonnage moved in single ship lots, minimizing the administrative effort associated with such a commodity related system.

Such a system would require a certain level of verification to insure accurate reporting of commodity and other data to the administration. Although requiring some effort, this could be done on a basis acceptable to both the user and administration.

Effect on the User

Prior to a change in tolls structure, serious consideration would need to be directed to the matter of impact on the user. The most significant difficulty regarding structuring of

tolls from the user's viewpoint is the question of distribution of burden. This problem develops if the level of tolls is above the direct cost of rendering service but below the value of service received. Under these circumstances, what relative share of the total costs of operating a canal should each user bear? Of course, each user will argue that his share should be lower. There are also such questions as the rich nations versus the poor. Where tolls place a burden on commodities from less developed nations, the exporters will maintain that their tolls burden should be least. Because of the many unknowns regarding the circumstances in which an administration will find itself when a sea-level canal is opened, it would be premature to speculate on a proper basis for distributing the burden. Accordingly, no findings regarding this matter have been reached.

There are additional considerations with which a canal administration would need to be concerned in selecting a tolls structure. There is, for example, the question of minimum impact of change. Most of the traffic for the sea-level canal will have previously used the existing Panama Canal. The rate structure then in existence for the Panama Canal will need to be considered. Whenever pricing systems are changed, it is usually desirable to minimize the extent of the change being made.

Chapter VI

CONCLUSIONS

The following are the major conclusions derived from this study:

1. Potential Isthmian canal total tonnage will increase at a diminishing rate from the 6.5 percent annual growth rate experienced by the present Panama Canal in the last 20 years.

2. Potential Isthmian canal total tonnage in the year 2000 is expected to be about 357 million tons, increasing to about 778 million tons in the year 2040. However, wide variations from these levels are possible over so long a forecast period.

3. The potential demands on the present Panama Canal will exceed its yearly capacity of 26,800 transits* in the period between 1989 and 2000.

4. The maximum number of potential annual transits forecast for the year 2000 is approximately 38,400. Maximum transit requirements for the year 2040, based on a conservative cargo tonnage growth estimate subsequent to the year 2000, are about 68,000. A slightly higher tonnage growth rate during the period 2000 to 2040, which is a distinct possibility, could result in approximately 100,000 transits by the year 2040.

5. A canal incapable of accommodating ships of 200,000 DWT or greater will not be fully competitive with such large ships on alternate routes and hence will not attract all potential canal traffic. A canal that could transit 250,000 DWT ships could accommodate all the ships projected for the world fleet in the year 2000 that would be likely to use an Isthmian canal. The minimum upper size limit that should be considered for initial construction is 150,000 DWT.

6. A pricing system for tolls designed to meet the competition of alternatives to the canal will attract the most traffic and generate the greatest revenues in a future canal of any type, lock or sea level. If necessary, selective increases averaging 50 percent over present tolls can be applied without markedly affecting traffic growth. Such increases would produce gross revenues approximately 40 percent greater than those attainable under the present tolls system.

*Estimated ultimate physical operating capacity, with major improvements to include augmentation of water supply.

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Appendix 1

METHODOLOGY FOR COMPUTATION OF PROJECTED CANAL TRAFFIC AND REVENUES

1. **Definitions**

a. **Total Potential Tons**: The total annual tonnage (long tons) that potentially would transit through an unrestricted Isthmian canal; projected to Year 2040, based on Panama Canal experience and other considerations.

b. **Cargo Mix**: Percentages of the total tonnage carried on each of the three major ship types–tank ships, dry bulk carriers (including dry bulk, combination dry bulk, and ore ships), and freighters (including general cargo, passenger, refrigerator, and container ships).

c. **Ship Efficiency**: The ratio of total cargo tonnage (long tons) to total deadweight tons (DWT); computed for each ship type, and based on Panama Canal experience for Fiscal Year 1968 and the first half of Fiscal Year 1969.

d. **Average DWT**: The average size ship (DWT) which would use an Isthmian canal; computed for each of the three ship types from world fleet size distribution projections, Panama Canal experience, and adjusted for the maximum size ship which could transit the canal option being considered.

e. **Average Toll per Ton**: The average toll per long ton of cargo; computed by weighting, in proportion to the cargo-mix, the average toll per ton of cargo for each type ship determined from current Panama Canal experience.

2. **Computations**

a. **Total Transits Required**

$$\text{Total transits} = \text{Total potential tons} \times \frac{\text{Tanker cargo mix}}{\text{(Efficiency)(Ave DWT)}} + \frac{\text{Bulker cargo mix}}{\text{(Efficiency)(Ave DWT)}} + \frac{\text{Freighter cargo mix}}{\text{(Efficiency)(Ave DWT)}}$$

b. **Total Tons Transmitted**

Total tons = 1) total potential tons, when total transits required are less than transit capacity of canal option considered.

or

= 2) $\text{Total potential tons} \times \frac{\text{Transit capacity}}{\text{Total transits required}}$

When total transits required are greater than transit capacity of the canal option considered.

c. **Total Annual Revenue**

Total revenue = (Total tons transited) (Average toll per ton)

3. Explanation

The five basic variables required for the computation of projected canal revenues are defined above (Sec. 1). These variables are related as shown in Sect. 2, to compute total annual revenue. These computations are repeated for landmark years through the period of interest. By changing the values assigned to the five variables, within judgmental constraints, the sensitivity of the revenue projections to these variables can be examined, and a range of reasonable revenue projections can be obtained for each canal option considered. A detailed explanation of the method for selection of the numerical values of the five variables is given in Section 4. Section 5 presents the results of this selection process. Section 6 gives the results of the computations, using the selected values for the five variables.

4. Determination of Total Potential Tons, Cargo Mix, Ship Efficiency, Average DWT, and Average Toll per Ton

a. **Total Potential Tons:** The total potential tonnage forecast is based primarily on an analysis of the historical relationship between time series growth of commercial cargo tonnage passing through the Panama Canal and the Gross Product growth of the geographic regions that contributed to this traffic. Projections were developed by correlation of selected regional cargo tonnage exports and forecasts of regional product growth. Special consideration was given to forecasts of economic growth of Japan and projections of canal traffic that might originate from that country. For further details on the potential tonnage forecast, see Appendix 3, Isthmian Canal Potential Tonnage Forecast. A lower tonnage forecast was developed under different assumptions and is presented for alternative revenue planning purposes.

b. **Cargo Mix:** The shipping fleet has been divided into three general classes: tankers, dry bulkers, and freighters. The three classes of ships are examined separately because they operate with different efficiencies, size distributions and average tolls per ton of cargo. A percentage of the total tonnage transited by ship type, defined here as the "cargo mix", is assigned for each ship type. The values for the early years of the revenue computations are based on current Panama Canal experience. The future cargo mixes selected are based on Panama Canal cargo trends and projections of future world fleet composition by type of vessel.

c. **Ship Efficiency:** Ship efficiency is defined for these purposes as the ratio of cargo tons transited through the canal per DWT of vessel. It relates ship cargo capacity (DWT) to transits in ballast, partially laden transits, and cargo density. Values for ship efficiency were computed from current Panama Canal experience. Freighters have a relatively low efficiency, since they carry a light density cargo as compared to the bulk product carriers. Tankers now have a lower efficiency than the dry bulkers because tankers make a large number of their transits in ballast.

Panama Canal records cargo tons and Panama Canal tons (PCT) but not DWT. Therefore a relation between PCT and DWT was required to compute efficiency in Panama Canal traffic. The DWT for certain ships transiting Panama Canal in 1966 were obtained.

From plots of DWT vs PCT, a general relationship was obtained for each type of ship. The results generally showed (with some exceptions for minor ship classes that 1 PCT = 2 DWT.

d. **Average DWT**: The cargo tonnage was assumed to be carried on average size ships (DWT) for each of the three classes of ships. The size of this average ship was determined from Panama Canal experience (FY 1968 and the first half of FY 1969) and its relationship to the world fleet, the canal configuration being considered (i.e., the maximum size ship that can pass the canal), and projections of world fleet size distribution.

The following idealized case will illustrate the procedure. The Maritime Adminstration has provided projections of the size distribution of the world fleet. Figure A-1-1 shows a hypothetical projection as a plot of DWT vs. Percent of ships with greater DWT. The average world fleet ship is indicated. The average size of this ship passing through the Panama Canal currently is shown at level "a".

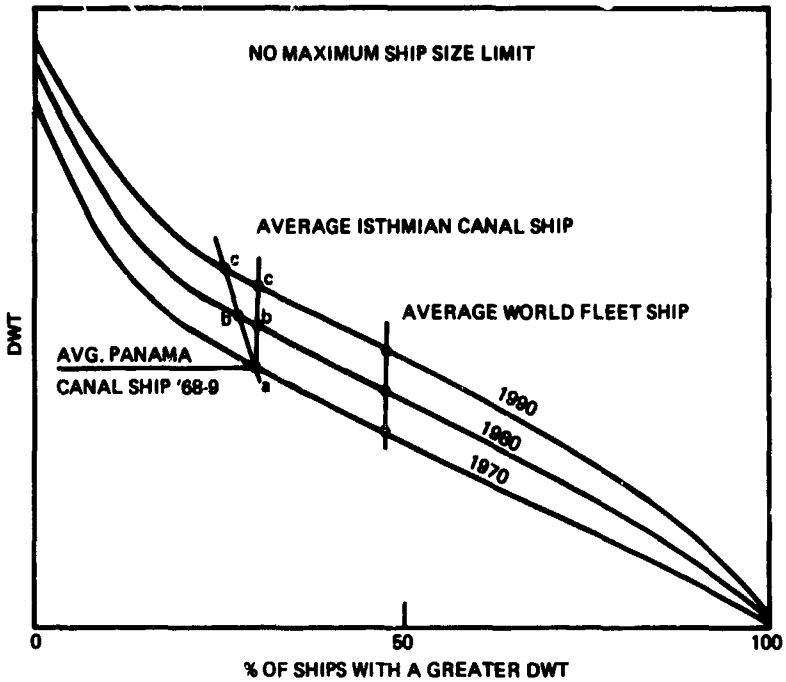
If it is assumed that the future Isthmian Canal traffic composition will continue in its current relationship to the world fleet composition, the average size canal ship will grow along line a-b-c. If the relationship is assumed to change, then the percentile of the world fleet size distribution in which the average canal ship lies will change. For instance, a modernized, large capacity canal may attract a greater percentage of large ships than does the current canal. In this case, the growth of the average ship size using the canal would follow a trend such as a-b-c.

One further modifying variable must be considered: maximum ship size that can pass through the canal. Various maximum ship sizes are considered to define and compare canal configurations. The largest ship size limitation does not affect average size of the relatively small freighters but it does affect the larger dry bulkers and tankers. Figure A1-2 illustrates the latter case. As before, the current size of the average ship passing through the Panama Canal is shown at Level "a". The growth represented by the line a-c-c again assumes that the average ship through the canal is in a constant percentile of the part of the world fleet smaller than the largest ship which could pass through the canal option under consideration.

e. **Average Toll per Ton**: The average toll per ton of cargo was computed by first considering the three types of ships separately. Tolls are based on Panama Canal Tons (PCT)–a measure of revenue producing space. (1 PCT = 100 cubic feet of actual earning capacity.) Because dry bulkers fill cargo space with dense cargo, they pay less tolls per ton of cargo than do freighters with their lighter cargoes. Tankers pay an intermediate rate because of their large number of ballast transits. Once the average toll per ton of cargo was computed from 1968 to 1969 canal experience for each type ship, an overall canal average was obtained by weighting each ship's rate by the corresponding cargo mix percentage.

5. Results–Total Potential Tons, Cargo Mix, Ship Efficiency, Average DWT, Average Toll per Ton

a. **General**: Prior to FY 1968, the Panama Canal commercial ocean traffic experience was recorded under four ship types--tankers, ore ships, passenger ships, and general cargo ships. Beginning in FY 1968, the ship classes were further subdivided to report separately combination carriers, container cargo ships, dry bulk carriers, and refrigerated cargo ships, in addition to ore, passenger, general cargo, and tank ships. These subdivisions allowed identification for the first time of the role of the three general ship classes established by the Maritime Administration and used in this study–freighters, dry bulkers, and tankers. All



FIGUE A1-1

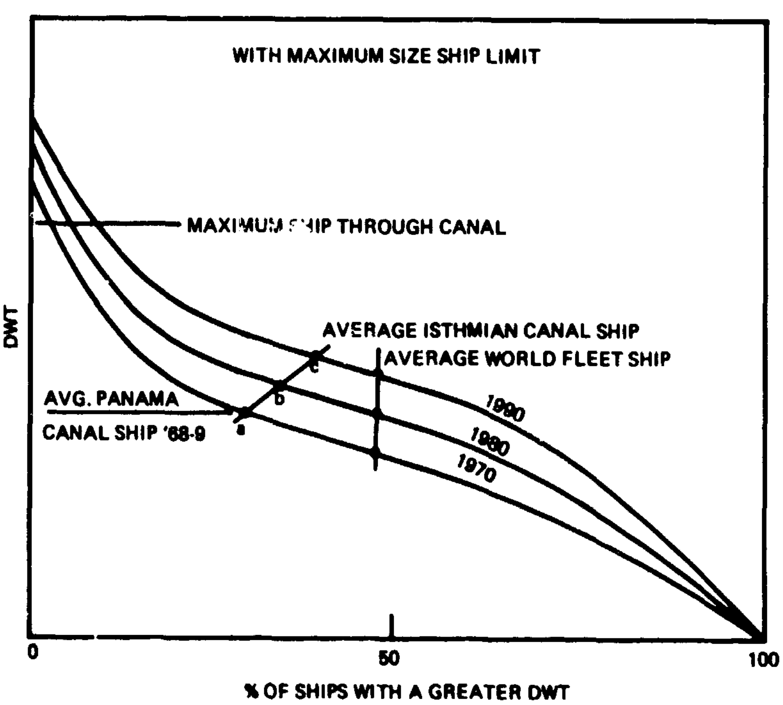


FIGURE A1-2

traffic other than commercial ocean traffic identified by these three ship classes has been included in the freighter class. On the average this other traffic has the same operating characteristics as do the commercial ocean freighters (i.e., similar efficiency, average DWT and average toll per ton). The analysis of cargo mix, ship efficiency, average DWT, and average toll per ton is thus largely based on FY 1968 and the first half of FY 1969 Panama Canal experience. The results of the 1968-1969 analysis for these four variables are given in Table A1-1. For the purposes of comparison, the records of commercial ocean traffic for 1951-67 were examined for two ship classes, general cargo ships and tankers. The results are presented in Table A1-2.

b. **Total Potential Tons:** Total potential cargo tonnages were taken from the potential tonnage forecast as described in Chapter IV and Appendix 3. This forecast was made by projecting forward a regression analysis of Panama Canal tonnage vs. Regional GNP back to 1950. A high correlation was established between regional product and the tonnage passing through the canal from the fifteen regions comprising the world. In the case of Japan, the present rate of growth was diminished to 5% in the year 2000 in anticipation of the diminishing of the present phenomenal rate of growth of its economy. To each value of the commercial ocean tonnage forecast, two million long tons were added as anticipated, peacetime government cargo. Lower cargo tonnages for alternative lower revenue planning purposes were taken from the low tonnage forecast described in Chapter IV. This forecast was made by projecting separate forecasts of Japan trade and all other commercial cargo, with an additional allowance for unforseeable trends. The two forecasts are summarized in Table A1-3.

c. **Cargo Mix:** The recent history of Panama Canal commercial ocean traffic cargo mix is plotted on Figure A1-3. The tank ship tonnage has shown a slow growth to a high of 22% of the total transited in 1965-67 with a 19 year average of 17%. The 1968-69 average of 17% has been selected for the projection of tanker cargo mix, and is assumed to remain constant through the period of interest. Figure A1-3 also shows the steady large role of the general cargo ship class until the dry bulker–freighter classification was first made in 1968. Two possible cargo mix projections were examined. The "46% Freighter Mix" assumes that current trends of the mix will continue throughout the future period. This is illustrated in Figure A1-4. The "25% Freighter Mix" shown in Figure A1-5 assumes a decline in the share of tonnage carried in freighters and a corresponding increase in that carried in bulkers. Assignment of an increase to tankers need not be considered since such an increase makes no significant difference in the end result of transits and revenues. The two cargo mix projections are recorded in Table A1-4. The implication of the 46% mix is a relatively large number of total transits as compared to the 25% mix.

d. **Ship Efficiency:** A Panama Canal Ton (PCT) was related to a deadweight ton (DWT) from a listing of 1966 Panama Canal traffic by ship name, type, PCT and DWT. The data are plotted in Figure A1-6. The relationship of PCT/DWT obtained showed that 1 PCT = 2 DWT for all major ship classes. (Exceptions: Passenger ships, 1 PCT = .6 DWT; container ships, 1 PCT = 1.1 DWT.)

Using the above relationships for PCT/DWT and current Panama Canal records of PCT and total cargo tonnage, the ship efficiencies listed in Tables A1-1 and A1-2 were computed. The general cargo ship efficiency remained quite stable during the period 1951-67, with an average of .51. The tanker efficiency varied between .4 and .6 as the relative number of

TABLE A1-1
PANAMA CANAL EXPERIENCE FY 1968 AND FIRST HALF FY 1969

Cargo Mix (%)	FY 1968	FY 1969 (First Half)	18 Month Average
Freighters	47	45	46
Bulkers	36	39	37
Tankers	17	16	17
Efficiency (Cargo Tons/DWT)			
Freighters	.41	.41	.41
Bulkers	.70	.73	.71
Tankers	.50	.47	.49
Average DWT			
Freighters	10,600	10,600	10,600
Bulkers	26,900	27,700	27,200
Tankers	17,800	18,000	17,900
Average Toll per Ton			
Freighters	$1.12	$1.12	$1.12
Bulkers	.60	.62	.61
Tankers	.83	.87	.84
All Ships	.88	.88	.88

NOTES: Bulkers are the dry bulk, combination dry bulk and ore ships included in commercial ocean traffic. Tankers are the tank ships included in commercial ocean traffic. Freighters are the general cargo, passenger, refrigerator, and container ships included in commercial ocean traffic, plus all other Panama Canal traffic not considered as bulkers and tankers.

ballast transits changed, with an average value of .53 for 1951-69. Although the past 18 months average (.49) is below the 19 year average, it is well within the range of past fluctuations, and has been assumed to prevail for the future projections. For freighters and dry bulkers, the last 18 month averages were also used—.41 for freighters and .71 for bulkers. The long term stability of the general cargo ship classification gives confidence to these values.

e. **Average DWT for a Sea-Level Canal**: Maritime Administration world fleet size distribution projections for each of three types of ships are plotted in Figures A1-7, 8 and 9. The world fleet average ship size is projected to grow along line WF. The current average Panama Canal ship for each ship type is indicated at level a-a. These average sizes were obtained from 1968-69 Panama Canal data and recorded in Table A1-1. Figures A1-10, A1-11, and A1-12 expand the portion of the previous figures in the range of the average canal ship. Again WF = World Fleet Average Ship and a-a is the present Panama Canal average. The growth of the average sea-level canal ship is indicated on the figures and is recorded in Table A1-5.

TABLE A1-2

PANAMA CANAL EXPERIENCE 1951-1967 COMMERCIAL OCEAN TRAFFIC

Fiscal Year	Cargo Mix (%)[1] General Cargo	Cargo Mix (%)[1] Tankers	Efficiency General Cargo	Efficiency Tankers	Average DWT General Cargo	Average DWT Tankers	Average Toll per Ton General Cargo	Average Toll per Ton Tankers	Average Toll per Ton All Ships
1951	76	10	.53	.55	9,300	12,700	$.83	$.74	$.79
1952	77	11	.55	.50	8,900	12,500	.81	.82	.80
1953	77	14	.51	.40	9,200	13,400	.87	.99	[illegible]
1954	80	12	.53	.42	9,200	13,200	.84	.95	.85
1955	77	16	.52	.56	9,000	13,600	.84	.74	.83
1956	76	16	.55	.55	9,200	14,900	.80	.75	.80
1957	78	12	.57	.54	9,500	15,000	.78	.76	.77
1958	74	14	.49	.49	9,600	15,900	.89	.83	.87
1959	70	18	.47	.51	9,700	16,700	.95	.80	.89
1960	[illegible]	18	.47	.55	9,700	17,800	.93	.75	.86
1961	71	19	.49	.59	10,200	19,000	.90	.72	.85
1962	73	19	.49	.59	10,600	18,800	.89	.71	.85
1963	70	21	.45	.58	10,700	17,100	.98	.72	.91
1964	72	[illegible]	.49	.61	10,700	17,600	.90	.69	.87
1965	71	22	.51	.55	11,300	18,500	.87	.76	.85
1966	72	22	.51	.55	11,900	19,300	.86	.76	.85
1967	74	22	.50	.49	12,900	20,100	.89	.84	.89

[1] Remainder of commercial ocean traffic carried in ore and passenger ships.

TABLE A1-3

TOTAL POTENTIAL TONNAGE
(Long Tons of Cargo)

Forecast	Tons (Millions) 1970	1980	1990	2000	2010	2020	2030	2040
Potential Tonnage	111	157	239	357	503	643	743	778
Low Tonnage	111	171	218	254	290	325	363	403

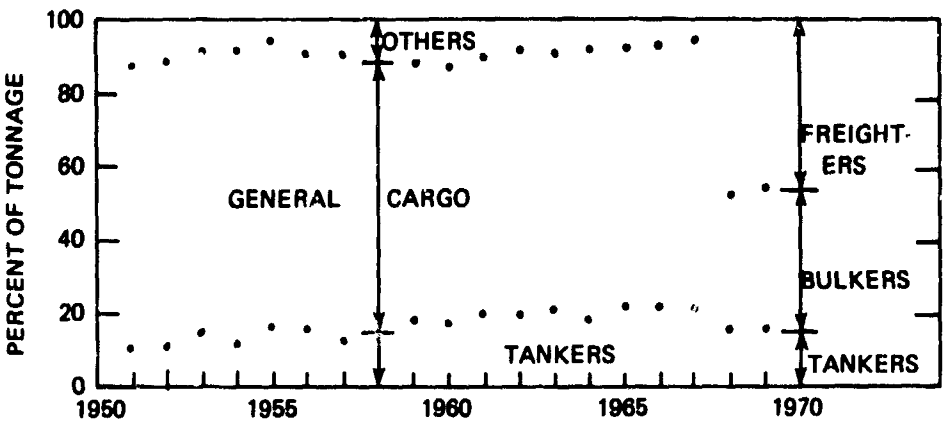
TABLE A1-4

CARGO MIX

Cargo Mix	Percentage of Total Potential Cargo Tons 1970	1980	1990	2000	2010	2020	2030	2040
"46% Freighter Mix"								
Freighters	46	46	46	46	46	46	46	46
Bulkers	37	37	37	37	37	37	37	37
Tankers	17	17	17	17	17	17	17	17
"25% Freighter Mix"								
Freighters	46	39	32	25	25	25	25	25
Bulkers	37	44	51	58	58	58	58	58
Tankers	17	17	17	17	17	17	17	17

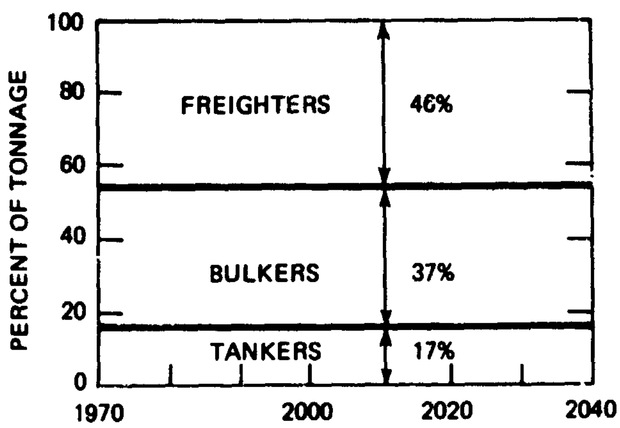
In the case of freighters, the present average canal freighter falls in the 33rd percentile of the world fleet distribution. This relationship is assumed to continue and the growth of the average freighter size in a sea-level canal will be along line a-b, Figure A1-10. The maximum size limitations of the Panama Canal and any sea-level canal are not expected to restrain this growth.

The present average Panama Canal bulker is in the 16th percentile of the world bulker fleet size distribution. It was assumed that the average size of the bulker would grow along the 16th percentile line of that part of the world fleet smaller than the design ship (i.e., 65,000 DWT for the present canal, up to 250,000 DWT for the largest canal). Thus, the growth of the average size bulker which would pass through a sea-level canal is expected to be modified by the maximum size ship that can be accommodated by the canal. With the present lock canal size limit of 65,000 DWT, the bulker average size will grow along line a-f, Figure A1-11. This growth is less than that for a larger canal, such as for a 250,000 DWT maximum ship case shown at a-b.



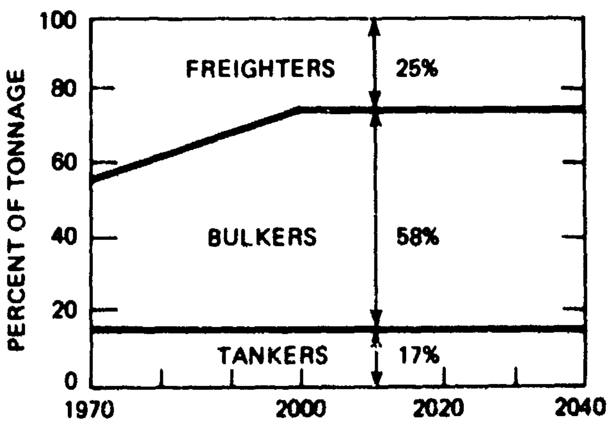
CARGO MIX-PANAMA CANAL

FIGURE A1-3



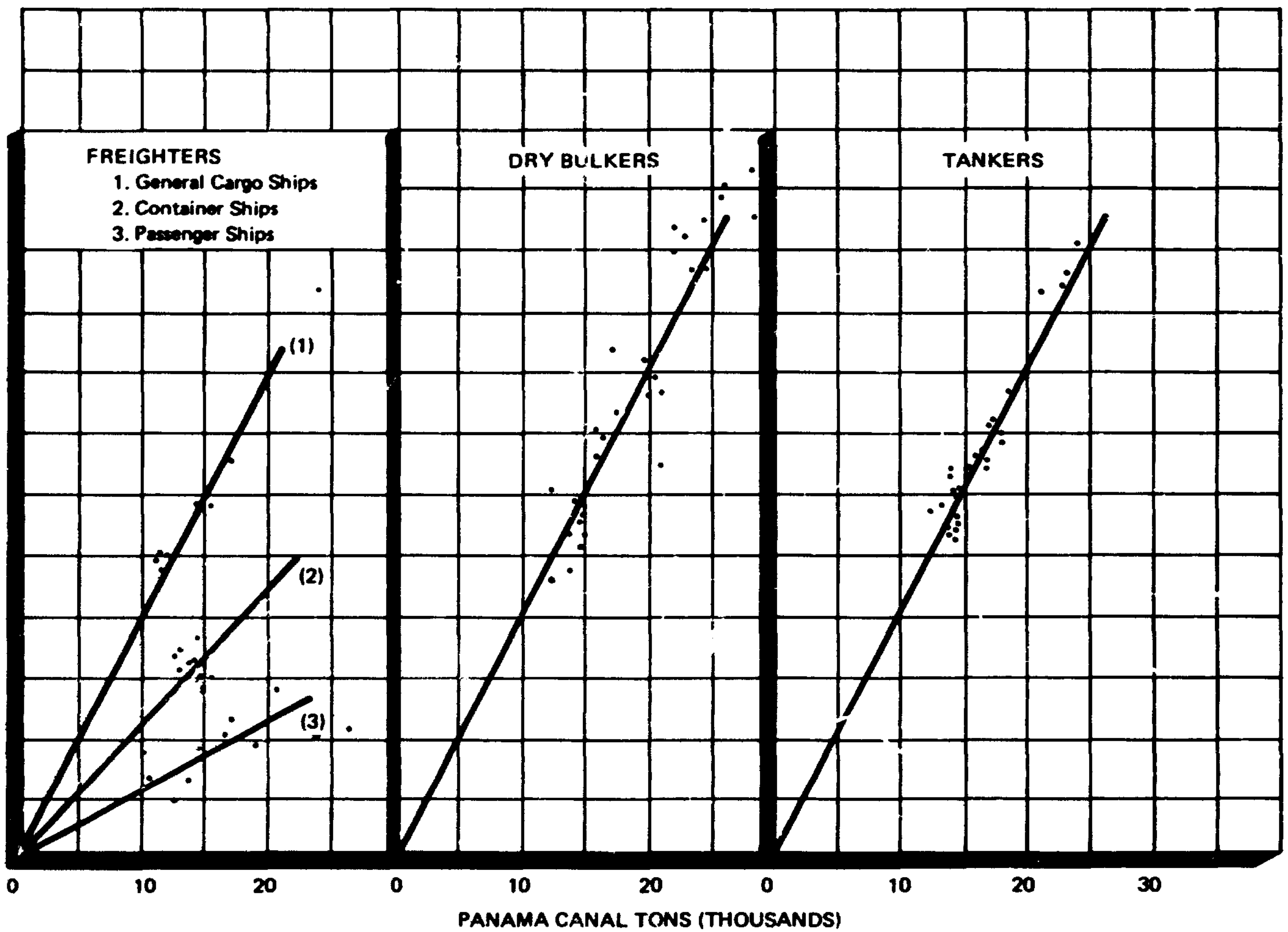
CARGO MIX 46% FREIGHTERS

FIGURE A1-4



CARGO MIX 25% FREIGHTERS

FIGURE A1-5



PANAMA CANAL TONS vs. DWT

FIGURE A1-6

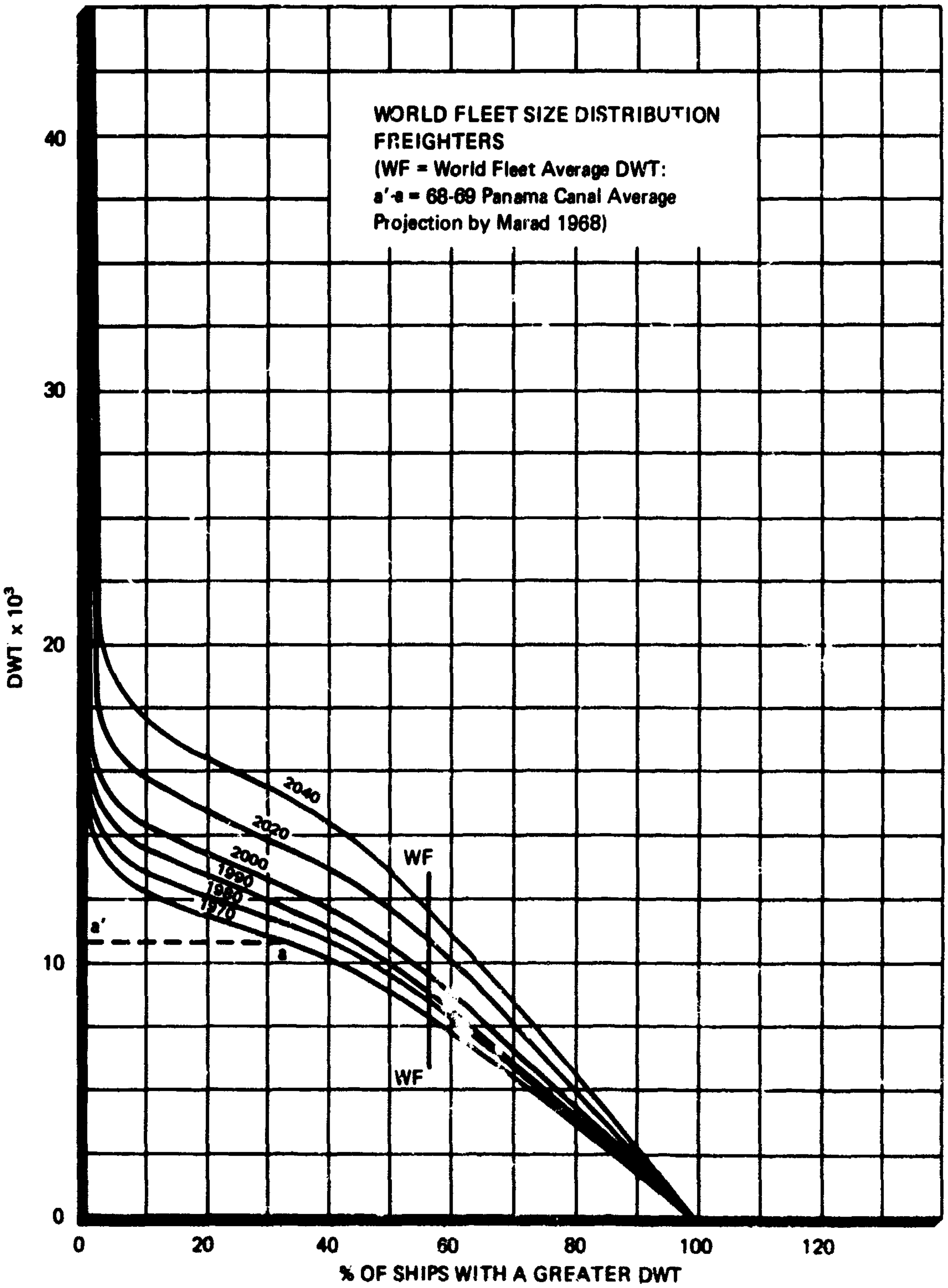
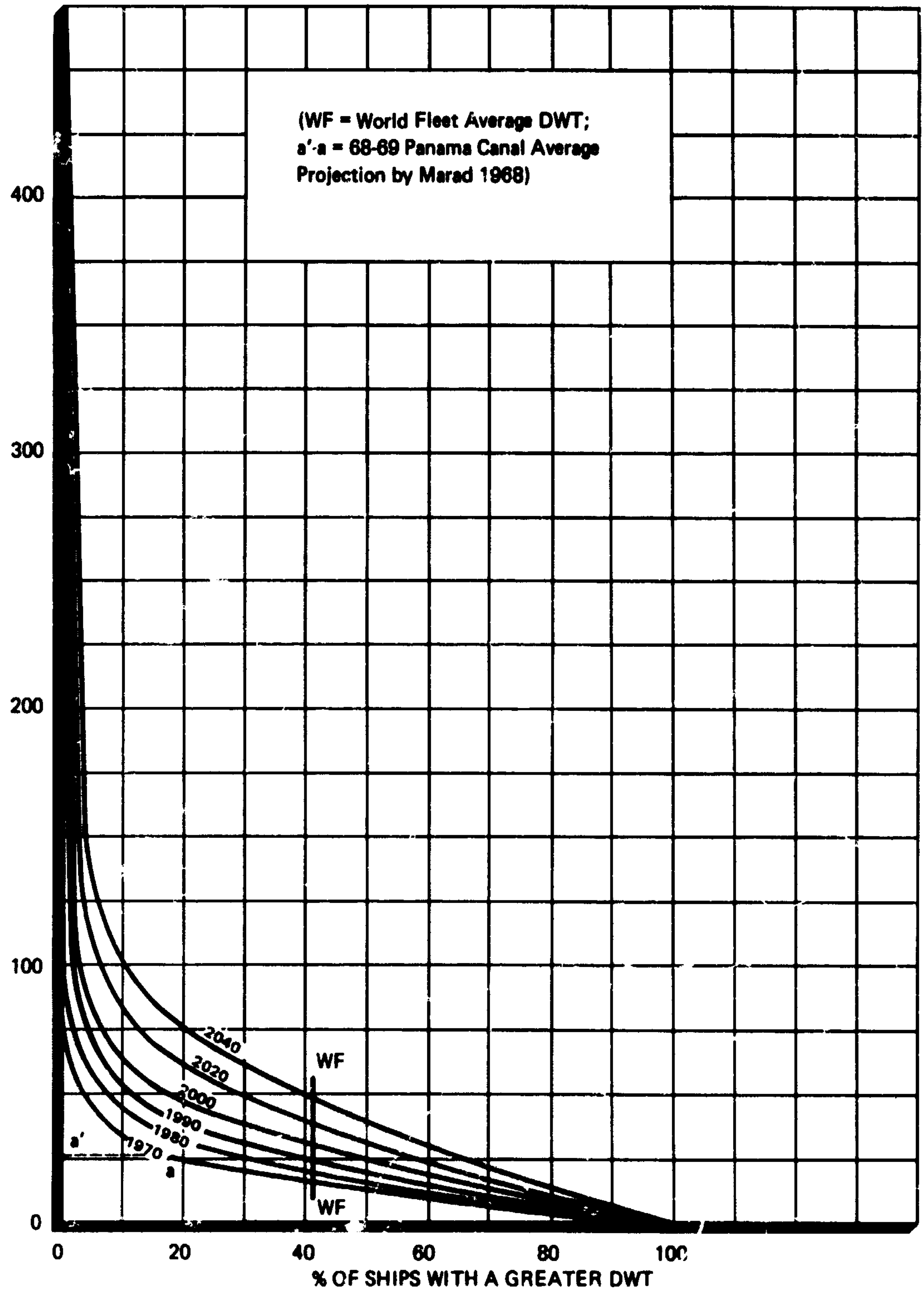
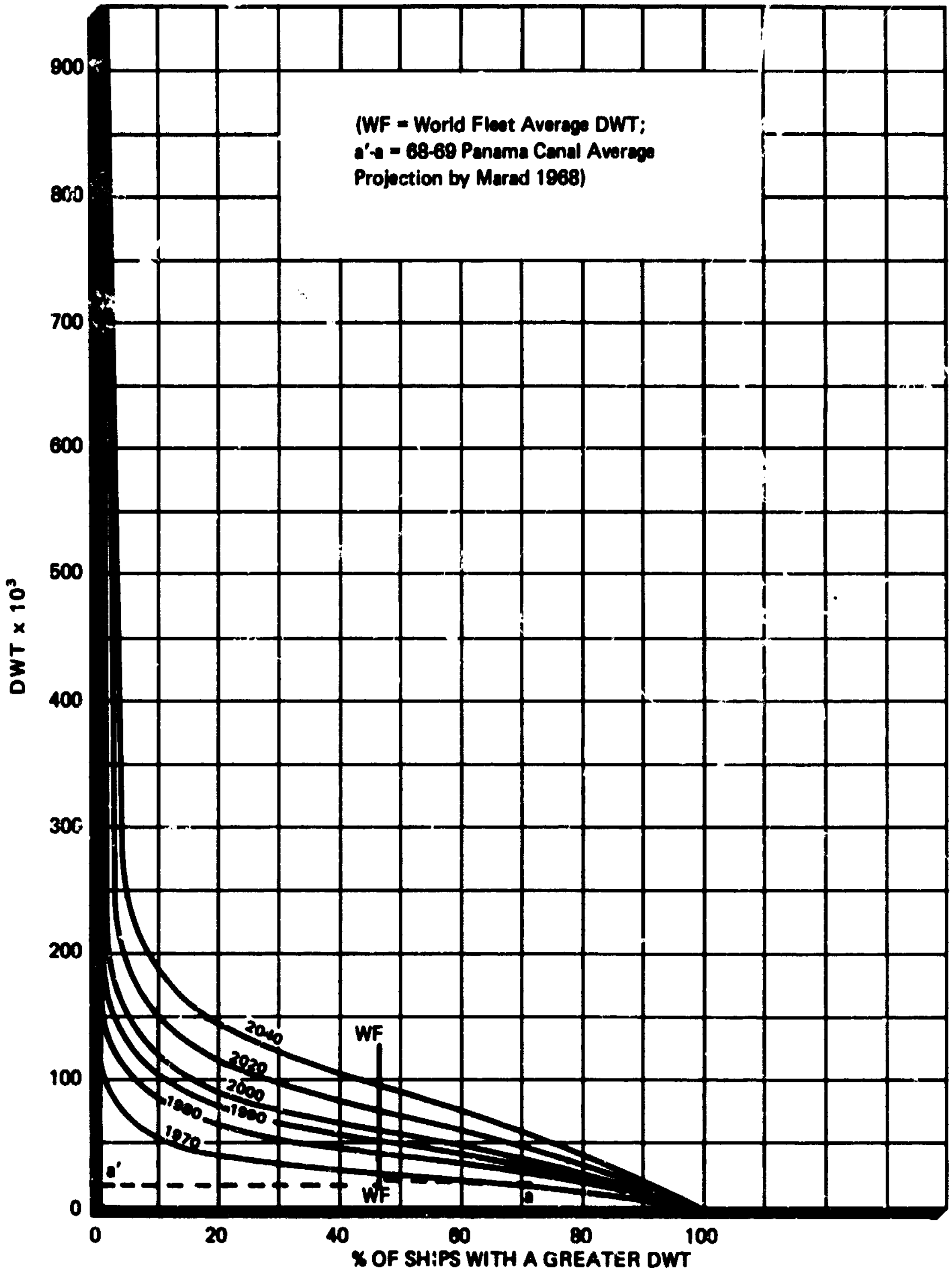

WORLD FLEET SIZE DISTRIBUTION
FREIGHTERS
(WF = World Fleet Average DWT:
a'-a = 68-69 Panama Canal Average
Projection by Marad 1968)
DWT x 10^3
% OF SHIPS WITH A GREATER DWT
2040
2020
2000
1990
1980
1970
WF
WF
a'
a
0
10
20
30
40
0
20
40
60
80
100
120

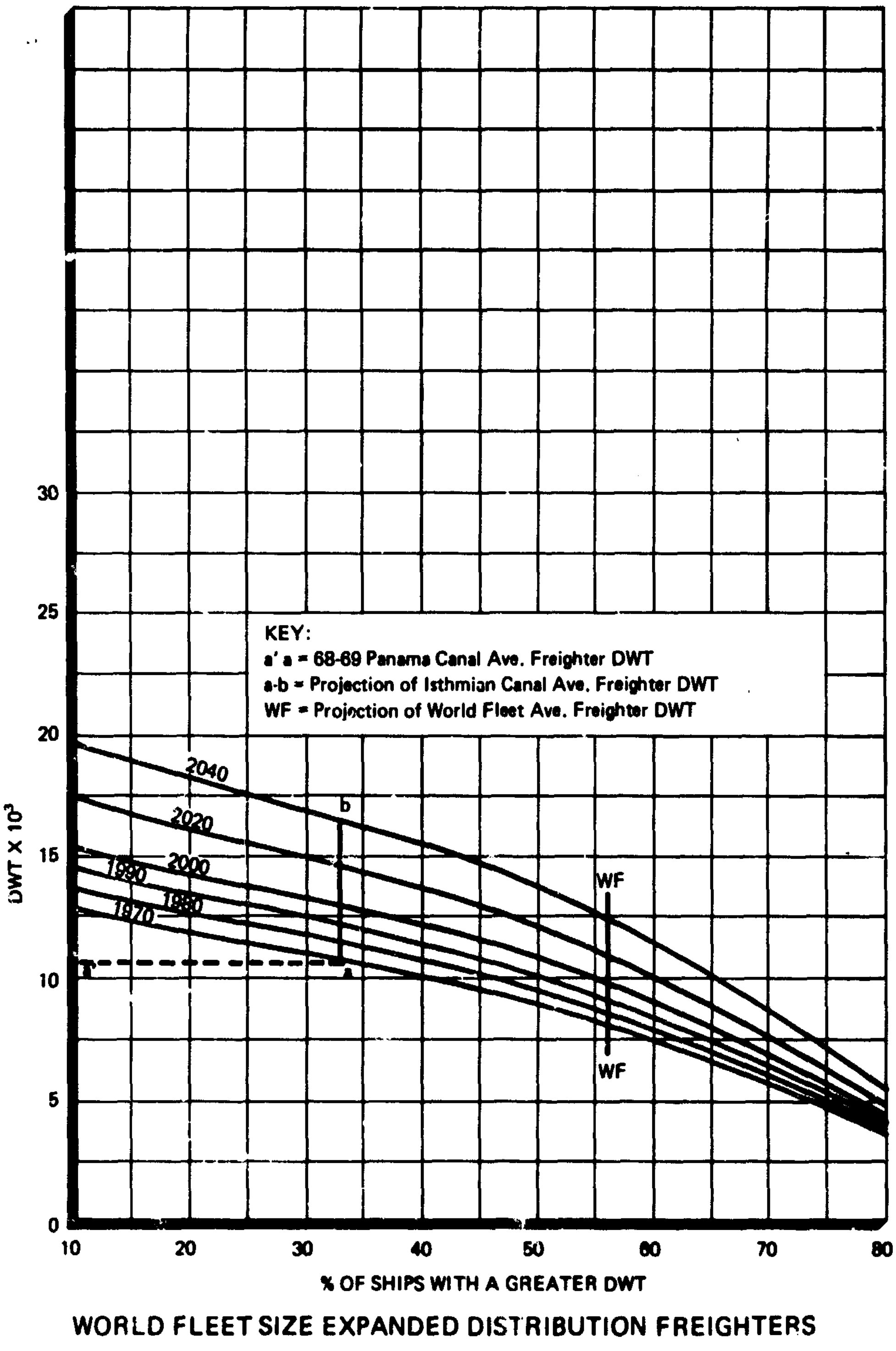
FIGURE A1-7



WORLD FLEET SIZE DISTRIBUTION DRY BULKERS
FIGURE A1-8

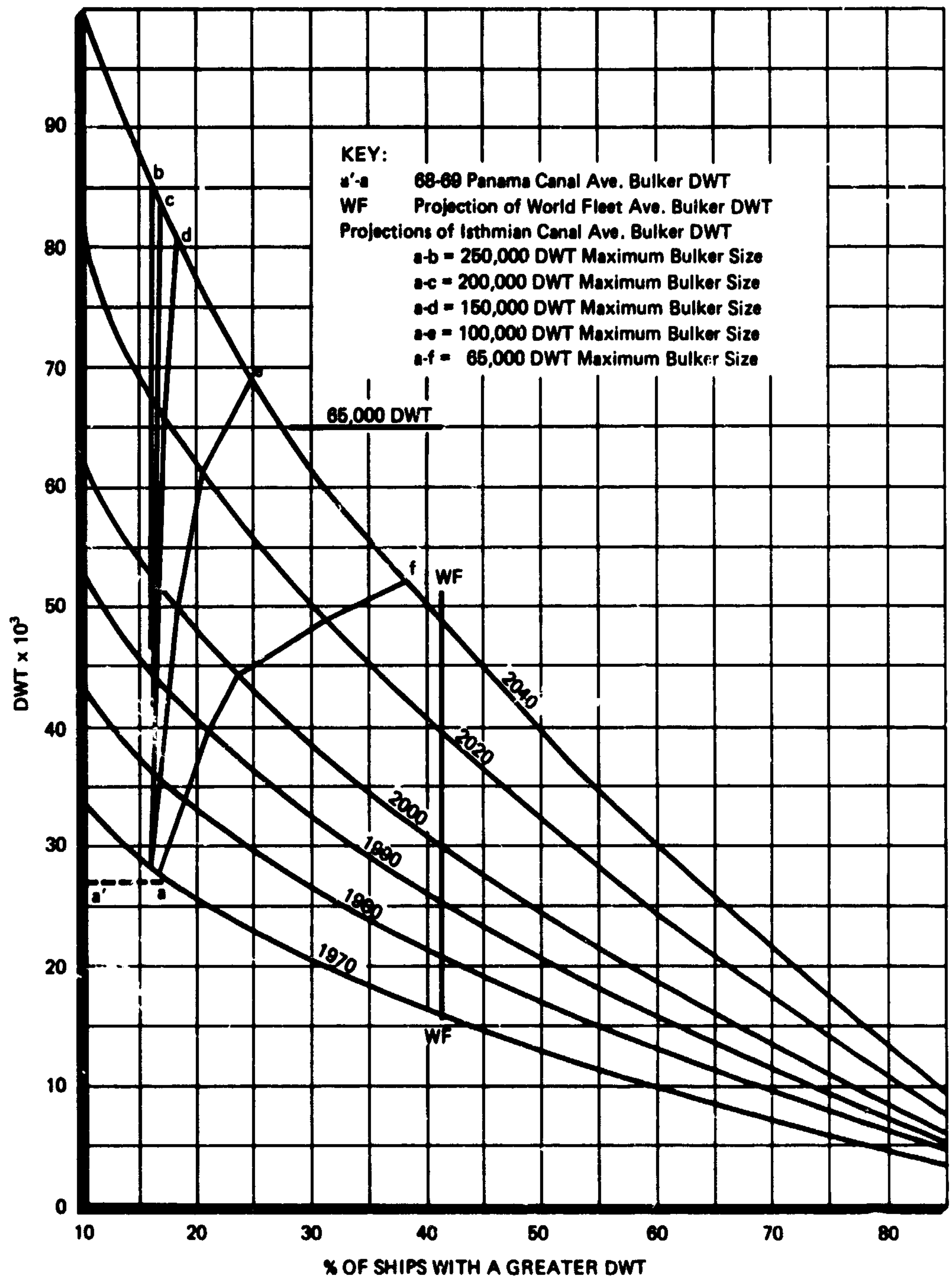


WORLD FLEET SIZE DISTRIBUTION TANKERS
FIGURE A1-9



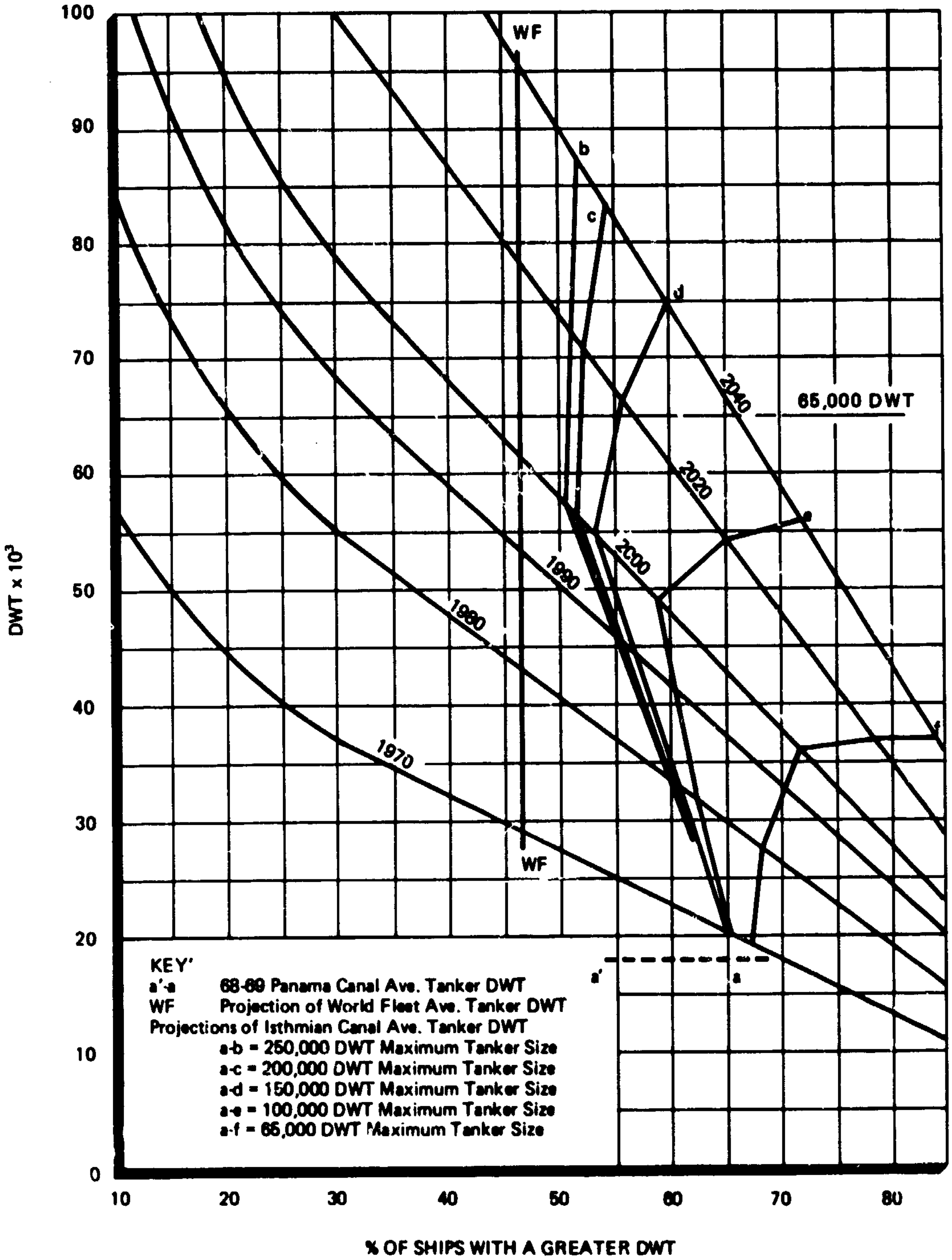
WORLD FLEET SIZE EXPANDED DISTRIBUTION FREIGHTERS

FIGURE A1-10



WORLD FLEET SIZE EXPANDED DISTRIBUTION
DRY BULKERS

FIGURE A1-11



WORLD FLEET SIZE EXPANDED DISTRIBUTION TANKERS

FIGURE A1-12

The same effect on growth is seen for tankers in Figure A1-12. However, in this case the present average canal tankers is in the 65th percentile. Since it is expected that the future average canal tanker will at least approach the median of that part of the world tanker fleet which can pass through the various canal options, the percentile in which the average canal tanker is placed was changed from 65% in 1970, to 60% in 1980, 55% in 1990, and to 50% in 2000 and thereafter.

f. **Average Toll per Ton of Cargo**: Tables A1-1 and A1-2 record the average toll per ton of cargo for each of the three types of ships from Panama Canal experience. The average toll for the canal as a whole is obtained by weighting the individual averages by the cargo mix percentage. Table A1-6 gives the results of these computations for the two cargo mixes considered.

6. Results–Computation of Transits Required and Projected Revenues

a. **General**: The computations of the transit requirements and projected revenues were carried out for the potential tonnage forecast, using the two cargo mixes selected, and for the low tonnage forecast with only the 46% freighter mix. For each combination of tonnage projection and cargo mix, the cargo was assumed to be carried on ships whose size was successively established at 65,000, 100,000, 150,000, 200,000 and 250,000 DWT. The 65,000 DWT limit corresponds to the present Panama Canal. A 26,800 annual transit capacity was used for this case. For the remaining maximum ship sizes no transit capacity was applied. Once the specific canal options and their transit capacities are established, these computations will be repeated to obtain revenue projections for each option.

b. **Transit Requirements**: Table A1-7 records the transit requirements for the various cases examined in connection with the potential tonnage forecast. These data are plotted in Figure A1-13. The top of each band is for the 65,000 DWT maximum ship size, and the bottom of the band is the 250,000 DWT case, with the remaining cases falling within the band. Transit requirements were also computed for the low tonnage forecast and are recorded in Table A1-7 and plotted with dotted lines in Figure A1-13. The low tonnage forecast assumes, among other factors, that a great volume of dry bulk cargoes in the higher potential tonnage forecast will not move through an interoceanic canal. Therefore, only the 46% freighter cargo mix is considered for purposes of transit requirements.

The following observations can be made concerning these data:

(1) The maximum ship size to be accommodated makes little difference in the number of transits required.

(2) The present Panama Canal transit capacity of 26,800 annual transits is reached between 1989 and 2000 for all cases considered in connection with the potential tonnage forecast; in the case of the low tonnage forecast, it is not reached until about the year 1997.

(3) The cargo mix has considerable effect on transit requirements.

c. **Revenue**: Potential revenue for the cases considered assuming no transit restrictions is plotted in Figure A1-14. The following comments apply to Figure A1-14.

(1) Revenue is not a function of maximum ship size accommodated, assuming the potential cargo will be loaded on ships that will go through the canal.

(2) The revenue is largely determined by the tonnage growth, and is less dependent on cargo mix than are the transit requirements.

TABLE A1-5
AVERAGE DWT PROJECTIONS

Ship Type	Maximum Ship Size	1970	1980	1990	2000	2020	2040
Freighter	All Limits	10,800	11,500	12,200	13,000	14,600	16,500
Bulker	65,000	27,800	33,900	39,800	44,400	48,800	52.000
	100,000	28,000	35,900	43,000	50,000	61,500	69,000
	150,000	28,000	36,000	43,700	51,600	65,800	81,000
	200,000	28,000	36,200	44,100	52,000	67,000	84,000
	250,000	28,000	36,200	44,100	52,200	67,200	85,000
Tanker	65,000	19,200	27,700	33,000	36,000	37,000	37,000
	100,000	20,000	31,800	41,600	49,200	54,300	56,000
	150,000	20,100	33,000	44,800	55,000	66,600	74,600
	200,000	20,100	33,300	45,500	56,600	71,000	83,200
	250,000	20,100	33,300	46,000	57,500	72,300	87,200

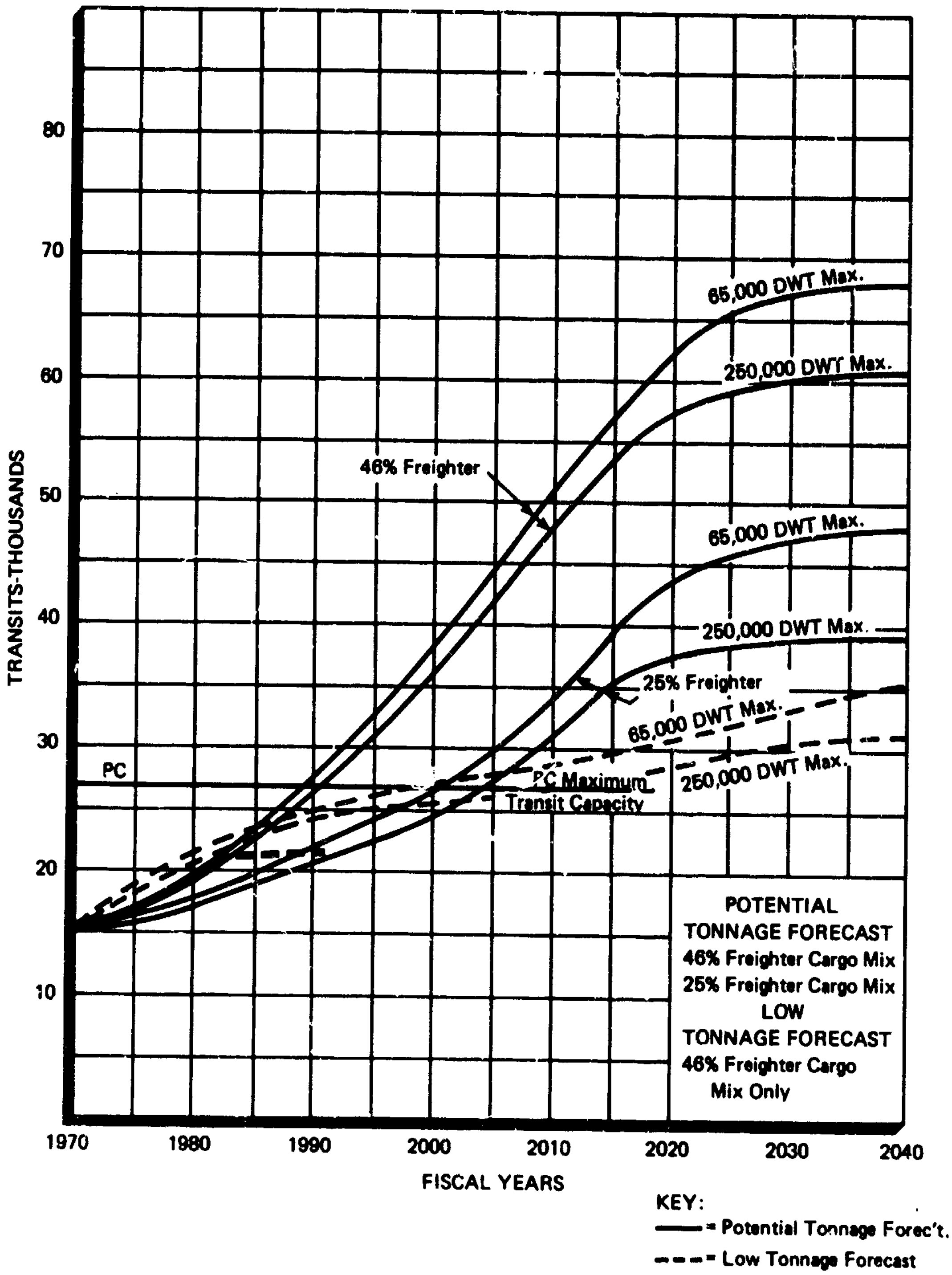
TABLE A1-6
PROJECTED AVERAGE TOLL PER TON

Cargo Mix	1970	1980	1990	2000	2020	2040
46% Freighter	$.884	$.884	$.884	$.884	$.884	$.884
25% Freighter	.884	.848	.812	.777	.777	777

TABLE A1-7

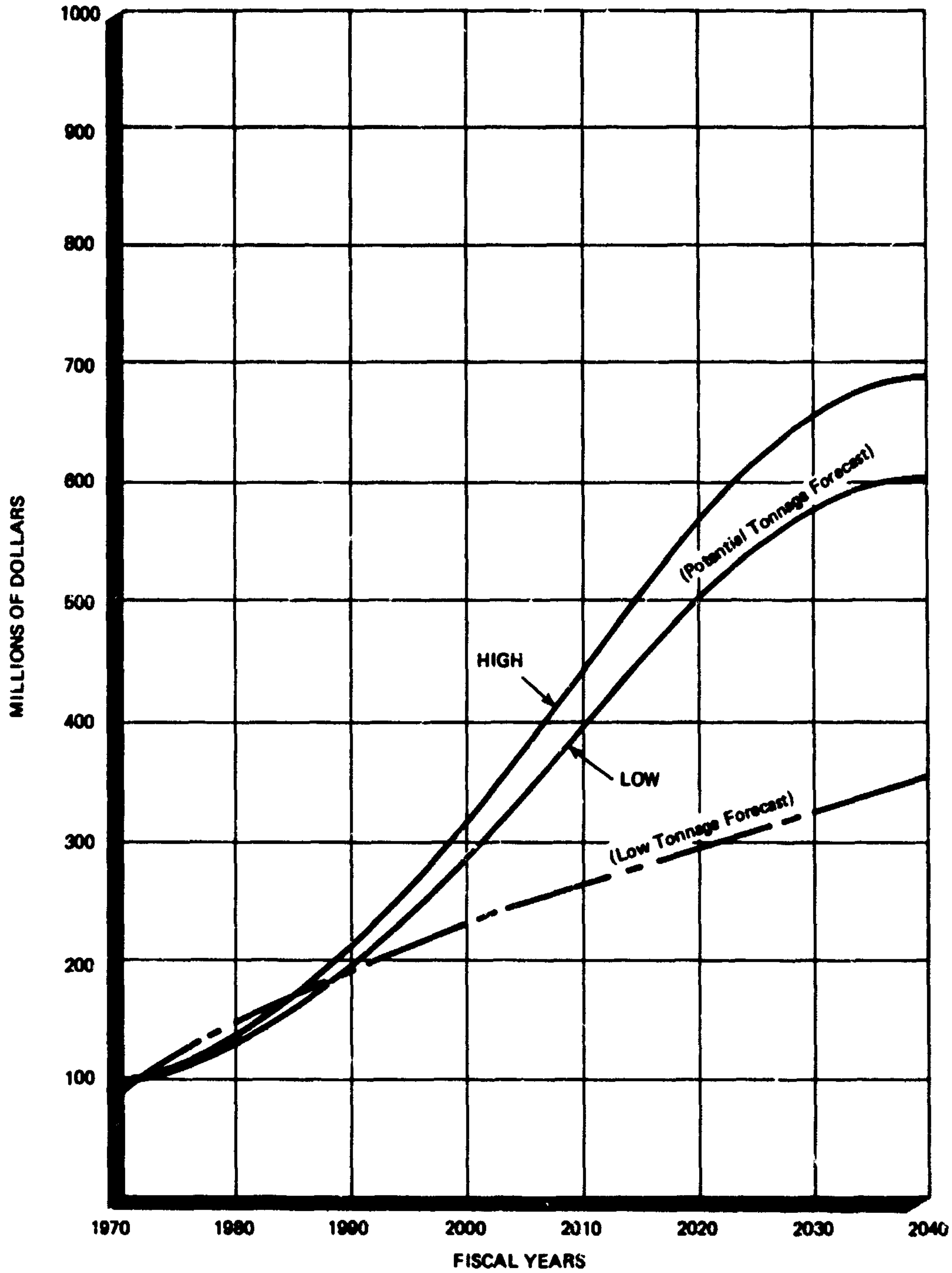
PROJECTED TRANSIT REQUIREMENTS
POTENTIAL TONNAGE FORECAST

Cargo Mix	Maximum Ship	1970	1980	1990	2000	2020	2040
46% Freighters	65,000 DWT	15,618	19,697	27,621	38,441	62,308	67,994
	100,000 DWT	15,523	19,309	26,869	37,049	58,969	63,598
	150,000 DWT	15,513	19,240	26,680	36,668	57,854	61,525
	200,000 DWT	15,513	19,213	26,626	36,577	57,555	60,973
	250,000 DWT	15,513	19,213	26,606	36,529	57,484	60,767
25% Freighters	65,000 DWT	15,561	17,823	22,116	26,754	43,647	48,268
	100,000 DWT	15,523	17,409	21,276	25,095	39,504	42,782
	150,000 DWT	15,513	17,339	21,069	24,649	38,187	40,215
	200,000 DWT	15,513	17,310	21,005	24,541	37,836	39,561
	250,000 DWT	15,513	17,310	20,985	24,486	37,756	39,323
				LOW TONNAGE FORECAST			
46% Freighters	65,000 DWT	15,618	21,453	25,194	27,350	31,493	35,220
	100,000 DWT	15,523	21,031	24,508	26,360	29,805	32,943
	150,000 DWT	15,513	20,956	24,336	26,089	29,242	31,870
	200,000 DWT	15,513	20,926	24,286	26,024	29,091	31,583
	250,000 DWT	15,513	20,926	24,286	25,990	29,055	31,477



ISTHMIAN CANAL TRANSIT PROJECTIONS

FIGURE A1-13



POTENTIAL REVENUES
ISTHMIAN CANAL WITH NO TRANSIT CAPACITY LIMITATIONS
BASED ON CURRENT PANAMA CANAL RATES

FIGURE A1-14

d. **Detailed Computations:** The detailed computations are recorded in Tables A1-8 through A1-25. Tables A1-8 through A1-13 use the potential tonnage forecast and 46% freighter cargo mix. Tables A1-14 through A1-19 use the same tonnages but use the 25% freighter cargo mix. Tables A1-20 through A1-25 use the low tonnage forecast and 46% freighter cargo mix. The following is an explanation of the table line items:

(1) The heading lists maximum ship size and maximum transit capacity (zero is used for no capacity limit).

(2) Line 1-Projected potential tonnage–using the potential tonnage forecast

(3) Lines 2-4–Cargo Mix–using either the 46% Freighter Mix or the 25% mix.

(4) Lines 5-7–Tons by ship type. (Lines 1x2=5; 1x3=6; 1x4=7).

(5) Lines 8-10–Ship Efficiencies.

(6) Lines 11-13–Total DWT by ship type. (Lines 5/8=11; 6/9=12; 7/10=13).

(7) Line 14–Total DWT all Ship (Lines 11+12+13).

(8) Lines 15-17–Average DWT by ship type.

(9) Lines 18-20–Transits by ship type (Lines 11/15=18; 12/16=19; 13/17=20).

(10) Line 21–Total transits (Lines 18+19+20).

(11) Line 22–Average DWT per transit (line 14/21).

(12) Line 23–Average cargo tons per transit (Line 1/21)

(13) Line 24–Average efficiency (Line 23/22)

(14) Line 25–Tons transited. (Line 1 when line 21 is less than maximum transit capacity; Line 1x (max. transits)/ Line 21 otherwise).

(15) Line 26–Average toll per ton of cargo.

(16) Line 27–Total Revenue (Line 25x26).

TABLE A1-8
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
POTENTIAL TONNAGE FORECAST
65000 DWT MAXIMUM SHIP SIZE
26800 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	157	239	357	643	778
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	37.0	37.0	37.0	37.0	37.0
4.	% FREIGHTER	46.0	46.0	46.0	46.0	46.0	46.0
5.	TONS TANKERS*	18.9	26.7	40.6	60.7	109.3	132.3
6.	BULKERS*	41.1	58.1	88.4	132.1	237.9	287.9
7.	FREIGHTERS*	51.1	72.2	109.9	164.2	295.8	357.9
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	54.5	82.9	123.9	223.1	269.9
12.	BULKERS*	57.8	81.8	124.5	186.0	335.1	405.4
13.	FREIGHTERS*	124.5	176.1	168.1	400.5	721.4	872.9
14.	TOTAL DWT ALL SHIPS*	221	312	476	710	1280	1548
15.	AVE DWT TANKERS	19200	27700	33000	36000	37000	37000
16.	BULKERS	27800	33900	39800	44400	48800	52000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	2006	1966	2513	3440	6029	7295
19.	BULKERS	2081	2413	3129	4190	6866	7797
20.	FREIGHTERS	11531	15317	21979	30811	49412	52902
21.	TOTAL TRANSITS	15618	19697	27621	38441	62308	67994
22.	AVE DWT/TRANSIT	14144	15862	17219	18481	20536	22770
23.	AVE TONS/TRANSIT	7107	7971	8653	9287	10320	11442
24.	AVE EFFICIENCY	0.503	0.503	0.503	0.503	0.503	0.503
25.	TONS TRANSITED*	111	157	232	249	277	307
26.	AVE TOLL/TON $	0.884	0.884	0.884	0.884	0.884	0.884
27.	TOTAL REVENUE $*	98.1	138.7	204.9	219.9	244.4	271.0

*MILLIONS

TABLE A1-9
COMPUTATION OF PORJECTED TRANSITS AND REVENUE
POTENTIAL TONNAGE FORECAST
65000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	157	239	357	643	778
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	37.0	37.0	37.0	37.0	37.0
4.	% FREIGHTER	46.0	46.0	46.0	46.0	46.0	46.0
5.	TONS TANKERS*	18.9	26.7	40.6	60.7	109.3	132.3
6.	BULKERS*	41.1	58.1	88.4	132.1	237.9	287.9
7.	FREIGHTERS*	51.1	72.2	109.9	164.2	295.8	357.9
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	54.5	82.9	123.9	223.1	269.9
12.	BULKERS*	57.8	81.8	124.5	186.0	335.1	405.4
13.	FREIGHTER*	124.5	176.1	268.1	400.5	721.4	872.9
14.	TOTAL DWT ALL SHIPS*	221	312	476	710	1280	1548
15.	AVE DWT TANKERS	19200	27700	33000	36000	37000	37000
16.	BULKERS	27800	33900	39800	44400	48800	52000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	2006	1966	2513	3440	6029	7295
19.	BULKERS	2081	2413	3129	4190	6866	7797
20.	FREIGHTERS	11531	15317	21979	30811	49412	52902
21.	TOTAL TRANSITS	15618	19697	27621	38441	62308	67994
22.	AVE DWT/TRANSIT	14144	15862	17219	18481	20536	22770
23.	AVE TONS/TRANSIT	7107	7971	8653	9287	10320	11442
24.	AVE EFFICIENCY	0.503	0.503	0.503	0.503	0.503	0.503
25.	TONS TRANSITED*	111	157	239	357	643	778
26.	AVE TOLL/TON $	0.884	0.884	0.884	0.884	0.884	0.884
27.	TOTAL REVENUE $*	98.1	138.7	211.2	315.5	568.2	687.5

*MILLIONS

TABLE A1-10
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
POTENTIAL TONNAGE FORECAST
100000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	157	239	357	643	778
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	37.0	37.0	37.0	37.0	37.0
4.	% FREIGHTER	46.0	46.0	46.0	46.0	46.0	46.0
5.	TONS TANKERS*	18.9	26.7	40.6	60.7	109.3	132.3
6.	BULKERS*	41.1	58.1	88.4	132.1	237.9	287.9
7.	FREIGHTERS*	51.1	72.2	109.9	164.2	295.8	357.9
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	54.5	82.9	123.9	223.1	269.9
12.	BULKERS*	57.8	81.8	124.5	186.0	335.1	405.4
13.	FREIGHTER*	124.5	176.1	268.1	400.5	721.4	872.9
14.	TOTAL DWT ALL SHIPS*	221	312	476	710	1280	1548
15.	AVE DWT TANKERS	20000	31800	41600	49200	54300	56000
16.	BULKERS	28000	35900	43000	50000	61500	69000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	1926	1713	1993	2517	4108	4820
19.	BULKERS	2066	2279	2896	3721	5449	5876
20.	FREIGHTERS	11531	15317	21979	30811	49412	52902
21.	TOTAL TRANSITS	15523	19309	26869	37049	58969	63598
22.	AVE DWT/TRANSIT	14230	16181	17701	19176	21699	24344
23.	AVE TONS/TRANSIT	7151	8131	8895	9636	10904	12233
24.	AVE EFFICIENCY	0.503	0.503	0.503	0.503	0.503	0.503
25.	TONS TRANSITED*	111	157	239	357	643	778
26.	AVE TOLL/TON $	0.884	0.884	0.884	0.884	0.884	0.884
27.	TOTAL REVENUE $*	98.1	138.7	211.2	315.5	568.2	687.5

*MILLIONS

TABLE A1-11
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
POTENTIAL TONNAGE FORECAST
150000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	157	239	357	643	778
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	37.0	37.0	37.0	37.0	37.0
4.	% FREIGHTER	46.0	46.0	46.0	46.0	46.0	46.0
5.	TONS TANKERS*	18.9	26.7	40.6	60.7	109.3	132.3
6.	BULKERS*	41.1	58.1	88.4	132.1	237.9	287.9
7.	FREIGHTERS*	51.1	72.2	109.9	164.2	295.8	357.9
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	54.5	82.9	123.9	223.1	269.9
12.	BULKERS*	57.8	81.8	124.5	186.0	335.1	405.4
13.	FREIGHTER*	124.5	176.1	268.1	400.5	721.4	872.9
14.	TOTAL DWT ALL SHIPS*	221	312	476	710	1280	1548
15.	AVE DWT TANKERS	20100	[illegible]	44800	55000	66600	74600
16.	BULKERS	28000	36000	43700	51600	65800	81000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	1916	1651	1851	2252	3350	3618
19.	BULKERS	2066	2273	2850	3605	5092	5005
20.	FREIGHTERS	11531	15317	21979	30811	49412	52902
21.	TOTAL TRANSITS	15513	19240	26680	36668	57854	61525
22.	AVE DWT/TRANSIT	14239	16238	17827	19375	22117	25164
23.	AVE TONS/TRANSIT	7155	8160	8958	9736	11114	12645
24.	AVE EFFICIENCY	0.503	0.503	0.503	0.503	0.503	0.503
25.	TONS TRANSITED*	111	157	239	357	643	778
26.	AVE TOLL/TON $	0.884	0.884	0.884	0.884	0.884	0.848
27.	TOTAL REVENUE $*	98.1	138.7	211.2	315.5	568.2	687.5

*MILLIONS

TABLE A1-12
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
POTENTIAL TONNAGE FORECAST
200000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	157	239	357	643	778
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	37.0	37.0	37.0	37.0	37.0
4.	% FREIGHTER	46.0	46.0	46.0	46.0	46.0	46.0
5.	TONS TANKERS*	18.9	26.7	40.6	60.7	109.3	132.3
6.	BULKERS*	41.1	58.1	88.4	132.1	237.9	287.9
7.	FREIGHTERS*	51.1	72.2	109.9	164.2	295.8	357.9
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	54.5	82.9	123.9	223.1	269.9
12.	BULKERS*	57.8	81.8	124.5	186.0	335.1	405.4
13.	FREIGHTER*	124.5	176.1	268.1	400.5	721.4	872.9
14.	TOTAL DWT ALL SHIPS*	221	312	476	710	1280	1548
15.	AVE DWT TANKERS	20100	33300	45500	56600	71000	83200
16.	BULKERS	28000	36200	44100	52000	67000	84000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	1916	1636	1822	2188	3142	3244
19.	BULKERS	2066	2260	2824	3578	5001	4827
20.	FREIGHTERS	11531	15317	21979	30811	49412	52902
21.	TOTAL TRANSITS	15513	19213	26626	36577	57555	60973
22.	AVE DWT. TRANSIT	14239	16262	17863	19423	22232	25392
23.	AVE TONS/TRANSIT	7155	8172	8976	9760	11172	12760
24.	AVE EFFICIENCY	0.503	0.503	0.503	0.503	0.503	0.503
25.	TONS TRANSITED*	111	157	239	357	643	778
26.	AVE TOLL/TON $	0.884	0.884	0.884	0.884	0.884	0.885
27.	TOTAL REVENUE $*	98.1	138.7	211.2	315.5	568.2	687.5

*MILLIONS

TABLE A1-13
COMPUTATION OF PROJECTED TRANSIT AND REVENUE
POTENTIAL TONNAGE FORECAST
250000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	157	239	357	643	778
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	37.0	37.0	37.0	37.0	37.0
4.	% FREIGHTER	46.0	46.0	46.0	46.0	46.0	46.0
5.	TONS TANKERS*	18.9	26.7	40.6	60.7	109.3	132.3
6.	BULKERS*	41.1	58.1	88.4	132.1	237.9	287.9
7.	FREIGHTERS*	51.1	72.2	109.9	164.2	295.8	357.9
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	54.5	82.9	123.9	223.1	269.9
12.	BULKERS*	57.8	81.8	124.5	186.0	335.1	405.4
13.	FREIGHTER*	124.5	176.1	268.1	400.5	721.4	872.9
14.	TOTAL DWT ALL SHIPS*	221	312	476	710	1280	1548
15.	AVE DWT TANKERS	20100	33300	46000	57500	72300	87200
16.	BULKERS	28000	36200	44100	52200	67200	85000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	1916	1636	1803	2154	3086	3095
19.	BULKERS	2066	2260	2824	3564	4986	4770
20.	FREIGHTERS	11531	15317	21979	30811	49412	52902
21.	TOTAL TRANSITS	15513	19213	26606	36529	57484	60767
22.	AVE DWT/TRANSIT	14239	16262	17876	19449	22260	25478
23.	AVE TONS/TRANSIT	7155	8172	8983	9773	11186	12803
24.	AVE EFFICIENCY	0.503	0.503	0.503	0.503	0.503	0.503
25.	TONS TRANSITED*	111	157	239	357	643	778
26.	AVE TOLL/TON $	0.884	0.884	0.884	0.884	0.884	0.884
27.	TOTAL REVENUE $*	98.1	138.7	211.2	315.5	568.2	687.5

*MILLIONS

TABLE A1-14
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
POTENTIAL TONNAGE FORECAST
650000 DWT MAXIMUM SHIP SIZE
26800 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	157	239	357	643	778
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	36.0	44.0	51.0	58.0	58.0	58.0
4.	% FREIGHTER	46.0	39.0	32.0	25.0	25.0	25.0
5.	TONS TANKERS*	18.9	26.7	40.6	60.7	109.3	132.3
6.	BULKERS*	40.0	69.1	121.9	207.1	372.9	451.2
7.	FREIGHTERS*	51.1	61.2	76.5	89.3	160.8	194.5
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	54.5	82.9	123.9	223.1	269.9
12.	BULKERS*	56.3	97.3	171.7	291.6	525.3	635.5
13.	FREIGHTER*	124.5	149.3	186.5	217.7	392.1	474.4
14.	TOTAL DWT ALL SHIPS*	219	301	441	633	1140	1380
15.	AVE DWT TANKERS	19200	27700	33000	36000	37000	37000
16.	BULKERS	27800	33900	39800	44400	48800	52000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	2006	1966	2513	3440	6029	7295
19.	BULKERS	2025	2870	4313	6568	10764	12222
20.	FREIGHTERS	11531	12986	15290	16745	26854	28751
21.	TOTAL TRANSITS	15561	17823	22116	26754	43647	48268
22.	AVE DWT/TRANSIT	14094	16895	19946	23667	26128	28587
23.	AVE TONS/TRANSIT	7133	8809	10807	13344	14732	16118
24.	AVE EFFICIENCY	0.506	0.521	0.542	0.564	0.564	0.564
25.	TONS TRANSITED*	111	157	239	357	395	432
26.	AVE TOLL/TON $	0.884	0.848	0.812	0.777	0.777	0.777
27.	TOTAL REVENUE $*	97.4	133.1	194.1	277.2	306.6	335.5

*MILLIONS

TABLE A1-15
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
POTENTIAL TONNAGE FORECAST
650000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	157	239	357	643	778
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	36.0	44.0	51.0	58.0	58.0	58.0
4.	% FREIGHTER	46.0	39.0	32.0	25.0	25.0	25.0
5.	TONS TANKERS*	18.9	26.7	40.6	60.7	109.3	132.3
6.	BULKERS*	40.0	69.1	121.9	207.1	372.9	451.2
7.	FREIGHTERS*	51.1	61.2	76.5	89.3	160.8	194.5
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	54.5	82.9	123.9	223.1	269.9
12.	BULKERS*	56.3	97.3	171.7	291.6	525.3	635.5
13.	FREIGHTER*	124.5	149.3	186.5	217.7	392.1	474.4
14.	TOTAL DWT ALL SHIPS*	219	301	441	633	1140	1380
15.	AVE DWT TANKERS	19200	27700	33000	36000	37000	37000
16.	BULKERS	27800	33900	39800	44400	48800	52000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	2006	1966	2513	3440	6029	7295
19.	BULKERS	2025	2870	4313	6568	10764	12222
20.	FREIGHTER	11531	12986	15290	16745	26854	28751
21.	TOTAL TRANSITS	15561	17823	22116	26754	43647	48268
22.	AVE DWT/TRANSIT	14094	16895	19946	23667	26128	28587
23.	AVE TONS/TRANSIT	7133	8809	10807	13344	14732	16118
24.	AVE EFFICIENCY	0.506	0.521	0.542	0.564	0.564	0.564
25.	TONS TRANSITED*	111	157	239	357	643	778
26.	AVE TOLL/TON $	0.884	0.848	0.812	0.777	0.777	0.777
27.	TOTAL REVENUE $*	97.4	133.1	194.1	277.2	499.4	604.2

*MILLIONS

TABLE A-16
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
POTENTIAL TONNAGE FORECAST
100000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	157	239	357	643	778
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	44.0	51.0	58.0	58.0	58.0
4.	% FREIGHTER	46.0	39.0	32.0	25.0	25.0	25.0
5.	TONS TANKERS*	18.9	26.7	40.6	60.7	109.3	132.2
6.	BULKERS*	41.1	69.1	121.9	207.1	372.1	451.2
7.	FREIGHTERS*	51.1	61.2	76.5	89.3	160.8	194.5
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.170	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	54.5	82.9	123.9	223.1	269.9
12.	BULKERS*	57.8	97.3	171.7	291.8	525.3	635.5
13.	FREIGHTER*	124.5	149.3	186.5	217.7	392.1	474.4
14.	TOTAL DWT ALL SHIPS*	221	301	441	633	1140	1380
15.	AVE DWT TANKERS	20000	31800	41600	49200	54300	56000
16.	BULKERS	28000	35900	43000	50000	61500	69000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	1926	1713	1993	2517	4108	4820
19.	BULKERS	2066	2710	3992	5833	8541	9211
20.	FREIGHTERS	11531	12986	15290	16745	26854	28751
21.	TOTAL TRANSITS	15523	17409	21276	25095	39504	42782
22.	AVE DWT/TRANSIT	14230	17296	20734	25231	28869	32253
23.	AVE TONS/TRANSIT	7151	9018	11234	14226	16277	18185
24.	AVE EFFICIENCY	0.503	0.521	0.542	0.564	0.564	0.564
25.	TONS TRANSITED*	111	157	239	357	643	778
26.	AVE TOLL/TON $	0.884	0.848	0.812	0.777	0.777	0.777
27.	TOTAL REVENUE $*	98.1	133.1	194.1	277.2	499.4	604.2

*MILLIONS

TABLE A1-17
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
POTENTIAL TONNAGE FORECAST
150000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	157	239	357	643	778
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	44.0	51.0	58.0	58.0	58.0
4.	% FREIGHTER	46.0	39.0	32.0	25.0	25.0	25.0
5.	TONS TANKERS*	18.9	26.7	40.6	60.7	109.3	132.3
6.	BULKERS*	41.1	69.1	121.9	207.1	372.9	451.2
7.	FREIGHTERS*	51.1	61.2	76.5	89.3	160.8	194.5
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	54.5	82.9	123.9	223.1	269.9
12.	BULKERS*	57.8	97.3	171.7	291.6	525.3	635.5
13.	FREIGHTER*	124.5	149.3	186.5	217.7	392.1	474.4
14.	TOTAL DWT ALL SHIPS*	221	301	441	633	1140	1380
15.	AVE DWT TANKERS	20100	33000	44800	55000	66600	74600
16.	BULKERS	28000	36000	43700	51600	65800	81000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	1916	1651	1851	2252	3350	3618
19.	BULKERS	2066	2703	3929	5652	7983	7846
20.	FREIGHTERS	11531	12986	15290	16745	26854	28751
21.	TOTAL TRANSITS	15513	17339	21069	24649	38187	40215
22.	AVE DWT/TRANSIT	14239	17365	20937	25688	29864	34312
23.	AVE TONS/TRANSIT	7155	9054	11344	15584	16838	19346
24.	AVE EFFICIENCY	0.503	0.521	0.542	0.564	0.564	0.564
25.	TONS TRANSITED*	111	157	239	357	643	778
26.	AVE TOLL/TON $	0.884	0.848	0.812	0.777	0.777	0.777
27.	TOTAL REVENUE $*	98.1	133.1	194.1	277.2	499.4	604.2

*MILLIONS

TABLE A1-18
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
POTENTIAL TONNAGE FORECAST
200000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	157	239	357	643	778
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	44.0	51.0	58.0	58.0	58.0
4.	% FREIGHTER	46.0	39.0	32.0	25.0	25.0	25.0
5.	TONS TANKERS*	18.9	26.7	40.6	60.7	109.3	132.3
6.	BULKERS*	41.1	69.1	121.9	207.1	372.9	451.2
7.	FREIGHTERS*	51.1	61.2	76.5	89.3	160.8	194.5
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	54.5	82.9	123.9	223.1	269.9
12.	BULKERS*	57.3	97.3	171.7	291.6	525.3	635.5
13.	FREIGHTER*	124.5	149.3	186.5	217.7	392.1	474.4
14.	TOTAL DWT ALL SHIPS*	221	301	441	633	1140	1380
15.	AVE DWT TANKERS	20100	33300	45500	56600	71000	83200
16.	BULKERS	28000	36200	44100	52000	67000	84000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	1916	1636	1822	2188	3142	3244
19.	BULKERS	2066	2688	3893	5608	7840	7566
20.	FREIGHTERS	11531	12986	15290	16745	26854	28751
21.	TOTAL TRANSITS	15513	17310	21005	24541	37836	39561
22.	AVE DWT/TRANSIT	14239	17395	21001	25800	30141	34879
23.	AVE TONS/TRANSIT	7155	9070	11378	14547	16994	19666
24.	AVE EFFICIENCY	0.503	0.521	0.542	0.564	0.564	0.564
25.	TONS TRANSITED*	111	157	239	357	643	778
26.	AVE TOLL/TON $	0.884	0.848	0.812	0.777	0.777	0.777
27.	TOTAL REVENUE $*	98.1	133.1	194.1	277.2	499.4	604.2

*MILLIONS

TABLE A1-19
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
POTENTIAL TONNAGE FORECAST
250000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	157	239	357	643	788
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	44.0	51.0	58.0	58.0	58.0
4.	% FREIGHTER	46.0	39.0	32.0	25.0	25.0	25.0
5.	TONS TANKERS*	18.9	26.7	40.6	60.7	109.3	132.3
6.	BULKERS*	41.1	69.1	121.9	207.1	372.9	451.2
7.	FREIGHTERS*	51.1	61.2	76.5	89.3	160.8	194.5
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.4[illegible]	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	54.5	82.9	123.9	223.1	269.9
12.	BULKERS*	57.8	97.3	171.7	291.6	525.3	635.5
13.	FREIGHTER*	124.5	149.3	186.5	217.7	392.1	474.4
14.	TOTAL DWT ALL SHIPS*	221	301	441	633	1140	1380
15.	AVE DWT TANKERS	20100	33300	46000	57500	72300	87200
16.	BULKERS	28000	36200	44100	52200	67200	85000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	1916	1636	1803	2154	3086	3095
19.	BULKERS	2066	2688	3893	5587	7816	7477
20.	FREIGHTERS	11531	12986	15290	16745	26854	28751
21.	TOTAL TRANSITS	15513	17310	20985	24486	37756	39323
22.	AVE DWT/TRANSIT	14239	17395	21021	25859	30205	35090
23.	AVE TONS/TRANSIT	7155	9070	11389	14580	17030	19785
24.	AVE EFFICIENCY	0.503	0.521	0.542	0.564	0.564	0.564
25.	TONS TRANSITED*	111	157	239	357	643	778
26.	AVE TOLL/TON $	0.884	0.848	0.812	0.777	0.777	0.777
27.	TOTAL REVENUE $*	98.1	133.1	194.1	277.2	499.4	604.2

*MILLIONS

TABLE A1-20
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
LOW TONNAGE FORECAST
65000 DWT MAXIMUM SHIP SIZE
26800 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	171	218	254	325	403
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	37.0	37.0	37.0	37.0	37.0
4.	% FREIGHTER	46.0	46.0	46.0	46.0	46.0	46.0
5.	TONS TANKERS*	18.9	29.1	37.1	43.2	55.3	68.5
6.	BULKERS*	41.1	63.3	80.7	94.0	120.3	149.1
7.	FREIGHTERS*	51.1	78.7	100.3	116.8	149.5	185.4
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	59.3	75.6	88.1	112.8	139.3
12.	BULKERS*	57.8	89.1	113.6	132.4	169.4	210.0
13.	FREIGHTER*	124.5	191.9	244.6	285.0	364.6	452.1
14.	TOTAL DWT ALL SHIPS*	221	340	434	505	647	802
15.	AVE DWT TANKERS	19200	27700	33000	36000	37000	37000
16.	BULKERS	27800	33900	39800	44400	48800	52000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	2006	2142	2292	2448	3047	3779
19.	BULKERS	3081	2629	2854	2981	3471	4039
20.	FREIGHTERS	11531	16683	20043	21921	24975	27403
21.	TOTAL TRANSITS	15618	21453	25194	27350	31493	35220
22.	AVE DWT/TRANSIT	14144	15862	17219	18481	20536	22770
23.	AVE TONS/TRANSIT	7107	7971	8653	9287	10320	11442
24.	AVE EFFICIENCY	0.503	0.503	0.503	0.503	0.503	0.503
25.	TONS TRANSITED*	111	171	218	249	277	307
26.	AVE TOLL/TON $	0.884	0.884	0.884	0.884	0.884	0.884
27.	TOTAL REVENUE $*	98.1	151.1	192.6	219.9	244.4	271.0

*MILLIONS

TABLE A1-21
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
LOW TONNAGE FORECAST
65000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	171	218	254	325	403
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	37.0	37.0	37.0	37.0	37.0
4.	% FREIGHTER	46.0	46.0	46.0	46.0	46.0	46.0
5.	TONS TANKERS*	18.9	29.1	37.1	43.2	55.3	68.5
6.	BULKERS*	41.1	63.3	80.7	94.0	120.3	149.1
7.	FREIGHTERS*	51.1	78.7	100.3	116.3	149.5	185.4
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	59.3	75.6	88.1	112.8	129.8
12.	BULKERS*	57.8	89.1	113.6	132.4	169.4	210.3
13.	FREIGHTER*	124.5	191.2	244.6	285.0	364.6	452.1
14.	TOTAL DWT ALL SHIPS*	221	340	434	505	647	802
15.	AVE DWT TANKERS	19200	27700	33000	36000	37000	37000
16.	BULKERS	27800	33900	39800	44400	48800	52000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	2006	2142	2292	2448	3047	3779
19.	BULKERS	3081	2629	2854	2981	3471	4039
20.	FREIGHTERS	11531	16683	20048	21921	24975	27403
21.	TOTAL TRANSITS	15618	21453	25194	27350	31493	35220
22.	AVE DWT/TRANSIT	14144	15862	17219	18481	20536	22770
23.	AVE TONS/TRANSIT	7107	7971	8653	9287	10320	11442
24.	AVE EFFICIENCY	0.503	0.503	0.503	0.503	0.503	0.503
25.	TONS TRANSITED*	111	171	218	254	325	403
26.	AVE TOLL/TON $	0.884	0.884	0.884	0.884	0.884	0.884
27.	TOTAL REVENUE $*	98.1	151.1	192.6	224.5	287.2	356.1

*MILLIONS

TABLE A1-22
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
LOW TONNAGE FORECAST
100000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	171	218	254	325	403
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	37.0	37.0	37.0	37.0	37.0
4.	% FREIGHTER	46.0	46.0	46.0	46.0	46.0	46.0
5.	TONS TANKERS*	18.9	29.1	37.1	43.2	55.3	68.5
6.	BULKERS*	41.1	63.3	80.7	94.0	120.3	149.1
7.	FREIGHTERS*	51.1	78.7	100.3	116.8	149.5	185.4
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	59.3	75.6	88.1	112.8	139.8
12.	BULKERS*	57.8	89.1	113.6	132.4	169.4	210.0
13.	FREIGHTERS*	124.5	191.9	244.6	285.0	364.6	452.1
14.	TOTAL DWT ALL SHIPS*	221	340	434	505	647	802
15.	AVE DWT TANKERS	20000	31800	41600	49200	54300	56000
16.	BULKERS	28000	35900	43000	50000	61500	69000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	1926	1866	1818	1791	2077	2497
19.	BULKERS	2066	2482	2642	2647	2754	3044
20.	FREIGHTERS	11531	16683	20048	21921	24975	27403
21.	TOTAL TRANSITS	15523	21031	24508	25360	29805	32943
22.	AVE DWT/TRANSIT	14230	16181	17701	19176	21699	24344
23.	AVE TONS/TRANSIT	7151	8131	8895	9636	10904	12233
24.	AVE EFFICIENCY	0.503	0.503	0.503	0.503	0.503	0.503
25.	TONS TRANSITED*	111	171	218	254	325	403
26.	AVE TOLL/TON $	0.884	0.884	0.884	0.884	0.884	0.884
27.	TOTAL REVENUE $*	98.1	151.1	192.6	224.5	287.2	346.1

*MILLIONS

TABLE A1-23
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
LOW TONNAGE FORECAST
150000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	171	218	254	325	403
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	37.0	37.0	37.0	37.0	37.0
4.	% FREIGHTER	46.0	46.0	46.0	46.0	46.0	46.0
5.	TONS TANKERS*	18.9	29.1	37.1	43.2	55.3	68.5
6.	BULKERS*	41.1	63.3	80.7	94.0	120.3	149.1
7.	FREIGHTERS*	51.1	78.7	100.3	116.8	149.5	185.4
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	59.3	75.6	88.1	112.8	139.8
12.	BULKERS*	57.8	89.1	113.6	132.4	169.4	210.0
13.	FREIGHTER*	124.5	191.9	244.6	285.0	364.6	452.1
14.	TOTAL DWT ALL SHIPS*	221	340	434	505	647	802
15.	AVE DWT TANKERS	20100	33000	44800	55000	66600	74600
16.	BULKERS	28000	36000	43700	51600	65800	81000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	1916	1798	1688	1602	1693	1874
19.	BULKERS	2066	2475	2600	2565	2574	2593
20.	FREIGHTERS	11531	16683	20048	21921	24975	27403
21.	TOTAL TRANSITS	15513	20956	24336	26089	29242	31870
22.	AVE DWT/TRANSIT	14239	16238	17827	19375	22117	25164
23.	AVE TONS/TRANSIT	7155	8160	8958	9736	11114	12645
24.	AVE EFFICIENCY	0.503	0.503	0.503	0.503	0.503	0.503
25.	TONS TRANSITED*	111	171	218	254	325	403
26.	AVE TOLL/TON $	0.884	0.884	0.884	0.884	0.884	0.884
27.	TOTAL REVENUE $*	98.1	151.1	192.6	224.5	287.2	356.1

*MILLIONS

TABLE A1-24
COMPUTATION OF PROJECTED TRANSITS AND REVENUES
LOW TONNAGE FORECAST
200000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	171	218	254	325	403
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	37.0	37.0	37.0	37.0	37.0
4.	% FREIGHTER	46.0	46.0	46.0	46.0	46.0	46.0
5.	TONS TANKERS*	18.9	29.1	37.1	43.2	55.3	68.5
6.	BULKERS*	41.1	64.3	80.7	94.0	120.3	149.1
7.	FREIGHTERS*	51.1	78.7	100.3	116.8	149.5	185.4
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	59.3	75.6	88.1	112.8	139.8
12.	BULKERS*	57.8	89.1	113.6	132.4	169.4	210.0
13.	FREIGHTER*	124.5	191.9	244.6	285.0	364.6	452.1
14.	TOTAL DWT ALL SHIPS*	221	340	434	505	647	802
15.	AVE DWT TANKERS	20100	33300	45500	56600	71000	83200
16.	BULKERS	28000	36200	44100	52000	67000	84000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	1916	1782	1662	1557	1588	1680
19.	BULKERS	2066	2462	2576	2546	2528	2500
20.	FREIGHTERS	11531	16683	20048	21921	24975	27403
21.	TOTAL TRANSITS	15513	20926	24286	26024	29091	31583
22.	AVE DWT/TRANSIT	14239	16262	17863	19423	22232	25392
23.	AVE TONS/TRANSIT	7155	8172	8976	9760	11172	12760
24.	AVE EFFICIENCY	0.503	0.503	0.503	0.503	0.503	0.503
25.	TONS TRANSITED*	111	171	218	254	325	403
26.	AVE TOLL/TON $	0.884	0.884	0.884	0.884	0.884	0.884
27.	TOTAL REVENUE $*	98.1	151.1	192.6	224.5	287.2	356.1

*MILLIONS

TABLE A1-25
COMPUTATION OF PROJECTED TRANSITS AND REVENUE
LOW TONNAGE FORECAST
250000 DWT MAXIMUM SHIP SIZE
0 MAXIMUM TRANSIT CAPACITY

	YEAR:	1970	1980	1990	2000	2020	2040
1.	TOTAL POTENTIAL TONS*	111	171	218	254	325	403
2.	CARGO MIX % TANKERS	17.0	17.0	17.0	17.0	17.0	17.0
3.	% BULKERS	37.0	37.0	37.0	37.0	37.0	37.0
4.	% FREIGHTER	46.0	46.0	46.0	46.0	46.0	46.0
5.	TONS TANKERS*	18.9	29.1	37.1	43.2	55.3	68.5
6.	BULKERS*	41.1	63.3	80.7	94.0	120.3	149.1
7.	FREIGHTERS*	51.1	78.7	100.3	116.8	149.5	185.4
8.	EFFICIENCY TANKERS	0.490	0.490	0.490	0.490	0.490	0.490
9.	BULKERS	0.710	0.710	0.710	0.710	0.710	0.710
10.	FREIGHTERS	0.410	0.410	0.410	0.410	0.410	0.410
11.	TOTAL DWT TANKERS*	38.5	59.3	75.6	88.1	112.8	139.8
12.	BULKERS*	57.8	89.1	113.6	132.4	169.4	210.0
13.	FREIGHTER*	124.5	181.9	244.6	285.0	364.6	452.1
14.	TOTAL DWT ALL SHIPS*	221	340	434	505	647	802
15.	AVE DWT TANKERS	20100	33300	46000	57500	72300	87200
16.	BULKERS	28000	36200	44100	52200	67200	85000
17.	FREIGHTERS	10800	11500	12200	13000	14600	16500
18.	TRANSITS TANKERS	1916	1782	1644	1533	1560	1603
19.	BULKERS	2066	2482	2578	2536	2520	2471
20.	FREIGHTERS	11531	16683	20048	21921	24975	27403
21.	TOTAL TRANSITS	15513	20926	24268	25990	29055	31477
22.	AVE DWT/TRANSIT	14239	16262	17876	19449	22260	25478
23.	AVE TONS/TRANSIT	7155	8172	8983	9773	11186	12803
24.	AVE EFFICIENCY	0.503	0.503	0.503	0.503	0.503	0.503
25.	TONS TRANSITED*	111	171	218	254	325	403
26.	AVE TOLL/TON $	0.884	0.884	0.884	0.884	0.884	0.884
27.	TOTAL REVENUE $*	98.1	151.1	192.6	224.5	287.2	356.1

*MILLIONS

Appendix 2

ANALYSIS OF PANAMA CANAL CARGO TONNAGE HISTORY

Purpose

The purpose of this Appendix is to provide additional, detailed data on Panama Canal cargo tonnage history and present the summary results of an analysis of these data. The requirements for new Isthmian canal facilities are based on projected increases in cargo tonnage that potentially would transit the canal. Such projections are based not only on the future outlook but on past experience. The tonnage history of the Panama Canal was therefore examined to identify trends in the growth of cargo tonnage. Certain important components of the total were examined to determine their individual growth rates and their contribution to the whole.

Data and Discussion

Tonnage data were derived from annual reports of the Panama Canal Company. Some of these data have already been presented in the summary discussion of Isthmian canal trade and the potential cargo tonnage forecast in Chapter IV and are not repeated in this Appendix. For reference purposes the following are pertinent:

Table IV-7:	Panama Canal Cargo Tonnage by Major Category, [illegible] – 1969
Figure IV-2:	Cargo Trends in [illegible] Canal
Table IV-9:	Major Trade Routes, Panama Canal Commercial Ocean Traffic, Selected Fiscal Years 1947 – 1969
Tables IV-10 and IV-11:	Comparison of Commercial Cargo Shipments to and from Asia with Other Traffic
Table IV-15:	Role of Japan in Panama Canal Traffic, Fiscal Years 1950 – 1969

An examination of the flow of Panama Canal traffic since World War II indicates that some fifteen "regional areas" serve as both origins and destinations for cargo shipments through the canal. For purposes of this portion of the analysis of Isthmian canal trade the "regional

areas" are identified as follows in order of importance with respect to volume of cargo by origin and destination, respectively, in Fiscal Year 1969:

Origin	Destination
East Coast USA	Japan
West Coast South America	East Coast USA
East Coast South America	Europe
Japan	West Coast USA
West Indies	West Coast South America
Europe	Asia (less Japan)
West Coast Canada	West Coast Central America/Mexico
West Coast USA	Oceania
Asia (less Japan)	West Coast Canada
Oceania	West Indies
West Coast Central America/Mexico	East Coast South America
East Coast Central America/Mexico	East Coast Canada
East Coast Canada	East Coast Central America/Mexico
Africa	Africa
Asia (Middle East)	Asia (Middle East)

Table A2-1 summarizes the flow of cargo tonnage from origin to destination for selected years during the period 1947–1969. It shows that since the mid-1950's the greatest increase by far in cargo tonnage shipments in any one direction is from the East Coast United States to Japan, increasing from approximately 5 million long tons of cargo in 1955 to over 27 million tons in 1969 (a growth rate of 13 per cent during this period). Cargo tonnage shipments from the East Coast United States to other Far East destinations have also demonstrated a high rate of growth during this same period (approximately 9.2 per cent). Shipments from most other origins to Japan while not in the same volume of those originating from East Coast United States ports, have also demonstrated a marked increase. Eastbound tonnage from Japan and other Far East origins to the East Coast United States have grown considerably in the past decade.

Although Japan and the other Far East destinations have exercised the greatest influence on the overall growth of canal traffic with respect to markets for cargo shipments, this has not been to the exclusion of significant growth along other trade routes. For example, cargoes originating in East Coast South American ports have shown a marked increase since 1950 in movements to the West Coast United States, West Coast Central America, and West Coast South America. Cargo shipments from the West Indies to the West Coast United States have increased significantly.

Table A2-2 summarizes commercial cargo movements to all destinations involved in canal traffic for Fiscal Years 1959 through 1969. The most outstanding feature is the remarkable increase in cargo movements (primarily from the East Coast United States) to Japan. It should also be noted that there has been an overall increase in traffic to virtually all other destinations.

TABLE A2-1

ORIGIN AND DESTINATION OF PANAMA CANAL TRAFFIC
SELECTED YEARS, 1947 - 1969
(000 Long Tons of Cargo)

	ATLANTIC-PACIFIC								
Origin/Destination	1947	1950	1955	1960	1965	1966	1967	1968	1969
East Coast USA									
– West Coast USA	1,736	2,093	2,648	2,260	3,181	3,328	3,328	2,994	2,581
– West Coast Canada	37	35	70	29	36	182	155	230	557
– West Coast Central America/Mexico	119	51	162	118	357	389	449	447	520
– West Coast South America	774	774	1,091	1,320	1,655	1,867	2,107	1,849	2,062
– Oceania	689	577	816	665	1,714	2,059	1,978	1,418	1,255
– Japan	483	1,868	4,959	9,772	14,644	16,242	20,105	24,299	27,326
– Asia (less Japan)	1,719	850	1,482	1,729	2,968	3,057	3,805	4,433	5,075
TOTAL	5,557	6,248	11,264	15,893	24,555	27,124	31,927	35,700	39,376
East Coast Canada									
– West Coast USA	54	43	15	17	37	32	21	24	24
– West Coast Canada	0	25	29	34	22	13	4	0	0
– West Coast Central America/Mexico	0	0	38	0	21	0	2	3	4
– West Coast South America	0	2	7	20	37	61	83	82	95
– Oceania	234	98	133	155	260	184	242	243	273
– Japan	0	0	[illegible]	242	495	320	448	527	751
– Asia (less Japan)	28	17	14	27	97	79	243	143	166
TOTAL	315	185	302	495	969	689	1,043	1,022	1,313

TABLE A2-1
ORIGIN AND DESTINATION OF PANAMA CANAL TRAFFIC
SELECTED YEARS, 1947 - 1969 (Cont'd.)
(000 Long Tons of Cargo)

	ATLANTIC-PACIFIC (Cont'd.)								
Origin/Destination	1947	1950	1955	1960	1965	1966	1967	1968	1969
East Coast Central America/Mexico									
– West Coast USA	5	1	2	24	33	24	113	222	277
– West Coast Canada	0	6	1	1	0	0	0	0	11
– West Coast Central America/Mexico	118	158	24	8	305	471	669	774	889
– West Coast South America	23	7	2	13	24	48	25	30	44
– Oceania	0	0	1	89	88	120	125	176	67
– Japan	0	0	1	1	91	166	89	107	152
– Asia (less Japan)	0	21	0	1	22	4	56	2	3
TOTAL	146	193	31	137	563	833	1,077	1,311	1,443
East Coast South America									
– West Coast USA	107	122	233	2,465	2,827	2,813	2,506	2,180	2,203
– West Coast Canada	27	22	2	6	110	235	118	135	321
– West Coast Central America/Mexico	9	0	105	357	1,273	1,474	1,639	1,846	2,017
– West Coast South America	30	58	463	1,041	1,941	2,748	3,181	3,557	3,859
– Oceania	0	1	111	119	206	34	104	40	5
– Japan	0	0	151	363	1,464	1,608	1,442	1,352	1,285
– Asia (less Japan)	0	0	0	0	16	90	155	84	26
TOTAL	173	203	1,065	4,351	7,837	9,002	9,145	9,195	9,176

TABLE A2-1

ORIGIN AND DESTINATION OF PANAMA CANAL TRAFFIC
SELECTED YEARS, 1947 - 1969 (Cont'd.)
(000 Long Tons of Cargo)

ATLANTIC-PACIFIC (Cont'd.)

Origin/Destination	1947	1950	1955	1960	1965	1966	1967	1968	1969
West Indies									
– West Coast USA	75	80	253	497	1,757	1,862	2,578	2,502	2,443
– West Coast Canada	24	19	125	308	425	469	411	328	472
– West Coast Central America/Mexico	364	257	508	692	513	388	474	459	602
– West Coast South America	858	520	1,108	790	952	803	816	677	587
– Oceania	72	71	263	233	194	44	43	3	20
– Japan	22	69	364	496	1,122	1,168	1,493	1,994	1,666
– Asia (less Japan)	25	16	64	158	254	370	418	390	448
TOTAL	1,440	1,032	2,685	3,174	5,217	5,104	6,233	6,353	6,238
Europe									
– West Coast USA	81	315	546	979	894	855	1,071	1,032	1,228
– West Coast Canada	48	118	197	298	260	245	316	266	307
– West Coast Central America/Mexico	49	76	263	282	376	344	369	378	392
– West Coast South America	216	298	667	848	967	1,265	1,288	1,177	1,251
– Oceania	240	722	1,185	773	903	920	827	843	882
– Japan	7	55	17	104	73	77	474	3,306	1,945
– Asia (less Japan)	10	15	6	78	15	10	23	133	155
TOTAL	651	1,599	2,881	3,362	3,488	3,716	4,368	7,135	6,160

TABLE A2-1

ORIGIN AND DESTINATION OF PANAMA CANAL TRAFFIC
SELECTED YEARS, 1947 - 1969 (Cont'd.)
(000 Long Tons of Cargo)

ATLANTIC-PACIFIC (Cont'd.)

Origin/Destination	1947	1950	1955	1960	1965	1966	1967	1968	1969
Asia (Middle East)									
– West Coast USA	0	11	116	5	12	11	14	9	10
– West Coast Canada	0	0	0	0	1	0	1	0	1
– West Coast Central America/Mexico	0	0	0	0	0	0	0	0	0
– West Coast South America	0	0	0	0	0	0	2	0	3
– Oceania	0	0	0	0	0	0	0	1	1
– Japan	0	0	0	7	0	0	0	22	0
– Asia (less Japan)	0	0	0	0	0	0	0	0	0
TOTAL	0	11	116	12	13	11	17	32	15
Africa									
– West Coast USA	0	5	37	124	180	112	109	28	57
– West Coast Canada	0	2	4	10	12	8	23	15	0
– West Coast Central America/Mexico	0	0	0	0	0	0	0	0	0
– West Coast South America	0	2	33	9	53	21	3	10	0
– Oceania	9	2	1	2	34	39	1	0	0
– Japan	0	0	0	4	17	13	41	557	433
– Asia (less Japan)	0	0	0	0	0	0	4	0	0
TOTAL	9	11	75	149	296	193	181	610	490

TABLE A2-1

ORIGIN AND DESTINATION OF PANAMA CANAL TRAFFIC
SELECTED YEARS, 1947 - 1969 (Cont'd.)
(000 Long Tons of Cargo)

	PACIFIC-ATLANTIC (Cont'd.)								
Origin/Destination	1947	1950	1955	1960	1965	1966	1967	1968	1969
West Coast USA									
– East Coast USA	1,665	6,221	4,149	5,104	2,642	2,459	1,825	1,719	1,271
– East Coast Canada	20	32	70	25	16	2	0	45	0
– East Coast Central America/Mexico	23	118	36	15	8	6	4	150	14
– East Coast South America	151	88	198	159	155	145	147	161	299
– West Indies	172	269	711	300	295	283	288	465	440
– Europe	1,852	808	1,465	2,672	2,438	2,917	2,492	2,424	2,538
– Asia (Middle East)	13	107	2	235	18	61	74	77	35
– Africa	101	116	180	110	97	161	112	77	38
TOTAL	3,997	7,759	6,811	8,620	5,672	6,034	4,942	5,188	4,635
West Coast Canada									
– East Coast USA	25	599	477	718	1,184	1,626	1,417	1,750	1,940
– East Coast Canada	0	13	95	44	9	6	6	3	0
– East Coast Central America/Mexico	0	10	1	2	1	0	0	0	11
– East Coast South America	39	18	47	109	340	216	153	131	161
– West Indies	26	28	98	90	122	124	131	150	167
– Europe	2,638	1,587	2,917	2,842	3,329	3,357	3,028	3,761	3,532
– Asia (Middle East)	29	128	70	29	37	38	53	56	33
– Africa	224	324	404	361	269	275	271	196	122
TOTAL	2,981	2,707	4,109	4,195	5,291	5,642	5,059	6,047	5,966

TABLE A2-1

ORIGIN AND DESTINATION OF PANAMA CANAL TRAFFIC
SELECTED YEARS, 1947 - 1969 (Cont'd.)

	PACIFIC-ATLANTIC (Cont'd.)								
Origin/Destination	1947	1950	1955	1960	1965	1966	1967	1968	1969
West Coast Central America/Mexico									
– East Coast USA	315	398	393	492	664	501	708	896	773
– East Coast Canada	5	0	0	2	0	0	16	0	1
– East Coast Central America/Mexico	72	63	48	59	96	41	20	9	15
– East Coast South America	3	7	5	29	30	19	15	101	103
– West Indies	15	11	11	8	11	12	17	11	31
– Europe	28	74	148	242	912	840	690	527	606
– Asia (Middle East)	0	4	0	0	0	0	0	0	0
– Africa	0	11	0	0	0	325	1	15	13
TOTAL	438	568	605	832	1,713	1,738	1,467	1,559	1,542
West Coast South America									
– East Coast USA	2,701	3,841	4,878	8,827	6,169	5,762	5,702	4,828	5,272
– East Coast Canada	8	0	9	368	103	91	78	17	30
– East Coast Central America/Mexico	53	18	9	26	49	73	76	123	128
– East Coast South America	43	58	55	74	42	49	68	93	112
– West Indies	86	37	35	37	33	35	92	241	99
– Europe	1,098	1,247	1,860	3,736	6,186	5,380	4,406	4,563	4,319
– Asia (Middle East)	10	13	20	55	28	11	29	11	24
– Africa	263	286	83	0	0	0	0	3	6
TOTAL	4,262	5,500	6,949	13,123	12,610	11,401	10,451	9,879	9,990

TABLE A2-1

ORIGIN AND DESTINATION OF PANAMA CANAL TRAFFIC SELECTED YEARS, 1947-1969 (Cont'd.)

(000 Long Tons of Cargo)

	PACIFIC-ATLANTIC (Cont'd.)								
Origin/Destination	1947	1950	1955	1960	1965	1966	1967	1968	1969
Oceania									
– East Coast USA	197	203	198	392	721	879	1,026	986	1,160
– East Coast Canada	66	88	127	168	201	206	291	234	366
– East Coast Central America/Mexico	0	2	1	6	19	15	19	21	21
– East Coast South America	0	6	1	9	12	8	10	11	17
– West Indies	4	33	27	51	72	77	191	458	158
– Europe	908	996	1,144	1,309	1,476	1,335	1,258	1,839	1,753
– Asia (Middle East)	0	0	0	0	0	0	0	3	2
– Africa	0	0	0	0	0	0	0	0	0
TOTAL	1,175	1,328	1,498	1,935	2,501	2,520	2,795	3,552	3,477
Japan									
– East Coast USA	49	211	490	947	2,813	4,153	4,041	4,790	5,592
– East Coast Canada	0	5	5	24	111	178	140	128	145
– East Coast Central America/Mexico	0	2	12	15	23	35	50	38	42
– East Coast South America	0	0	47	134	310	266	292	279	452
– West Indies	0	0	6	34	106	122	119	151	160
– Europe	0	0	23	63	87	116	118	568	941
– Asia (Middle East)	0	0	0	0	0	0	10	0	2
– Africa	0	0	0	0	2	6	1	9	63
TOTAL	49	218	583	1,217	3,452	4,876	4,771	5,963	7,397

TABLE A2-1

ORIGIN AND DESTINATION OF PANAMA CANAL TRAFFIC
SELECTED YEARS, 1947 - 1969 (Cont'd.)
(000 Long Tons of Cargo)

PACIFIC-ATLANTIC (Cont'd.)

Origin/Destination	1947	1950	1955	1960	1965	1966	1967	1968	1969
Asia (less Japan)									
– East Coast USA	463	1,280	1,388	1,612	2,115	2,451	2,327	2,487	2,788
– East Coast Canada	0	6	7	24	36	54	82	80	125
– East Coast Central America/Mexico	2	5	1	35	21	28	23	24	27
– East Coast South America	5	12	200	52	59	52	59	45	27
– West Indies	0	0	29	8	104	187	160	319	521
– Europe	3	0	28	0	40	49	61	111	145
– Asia (Middle East)	0	3	0	0	0	0	0	0	0
– Africa	0	1	18	0	0	0	0	2	1
TOTAL	473	1,307	1,671	1,731	2,375	2,821	2,712	3,068	3,634

SOURCE: Panama Canal Company Annual Reports

TABLE A2-2

SUMMARY OF DESTINATION OF PANAMA CANAL COMMERCIAL OCEAN TRAFFIC ALONG MAJOR TRADE ROUTES
FISCAL YEARS 1959 - 1969
(000 Long Tons of Cargo)

ATLANTIC-PACIFIC

FY	West Coast[1] USA	West Coast Canada	West Coast[2] Central America Mexico	West Coast South America	Oceania[3]	Japan	Asia (less Japan)	Total
1959	5,626	523	1,326	3,354	1,968	7,973	1,675	22,445
1960	6,372	686	1,457	4,039	2,037	10,991	1,992	27,574
1961	7,743	679	1,684	4,571	3,044	14,204	2,522	34,447
1962	7,224	526	1,926	5,108	2,527	16,504	3,893	37,708
1963	6,809	539	2,241	4,842	2,380	13,698	2,578	33,087
1964	6,928	627	2,625	4,816	2,857	17,784	3,264	38,901
1965	8.921	865	2,846	5,628	3,399	17,905	3,373	42,937
1966	9,038	1,151	3,066	6,813	3,400	19,594	3,609	46,671
1967	9,740	1,028	3,602	7,505	3,321	24,092	4,705	53,993
1968	8,990	975	3,939	7,382	2,724	32,164	5,186	61,360
1969	8,823	1,668	4,423	7,901	2,504	33,558	5,874	64,751

Notes:

[1] Includes Alaska and Hawaii

[2] Includes Balboa, Canal Zone

[3] Includes Australia, New Zealand and British and French Oceania

SOURCE: Panama Canal Company Annual Reports

TABLE A2-2

SUMMARY OF DESTINATION OF PANAMA CANAL COMMERCIAL OCEAN TRAFFIC ALONG MAJOR TRADE ROUTES FISCAL YEARS 1959 - 1969 (Cont'd.)

(000 Long Tons of Cargo)

PACIFIC-ATLANTIC

Fiscal Year	East Coast[4] USA	East Coast Canada	East Coast[5] Central America Mexico	East Coast South America	West Indies	Europe	Asia (Middle East)	Africa	Total
1959	16,125	317	129	522	926	10,063	107	520	28,709
1960	18,094	655	160	566	528	10,891	320	471	31,685
1961	14,393	800	158	566	567	11,751	512	475	29,222
1962	16,007	584	133	523	625	11,352	163	430	29,817
1963	14,362	617	168	641	655	12,266	44	407	29,160
1964	15,379	537	180	693	621	13,862	58	318	31,648
1965	16,309	477	226	948	745	14,468	84	368	33,625
1966	17,830	537	198	754	841	13,994	110	767	35,031
1967	17,045	613	192	743	998	12,053	172	385	32,201
1968	17,456	507	364	820	1,798	13,794	148	303	35,190
1969	18,796	667	257	1,172	1,576	13,833	97	243	36,641

Notes:

[4] Includes North Atlantic, South Atlantic, Gulf and Great Lakes Ports

[5] Includes Cristobal, Canal Zone

SOURCE: Panama Canal Company Annual Reports

Statistical Analysis

Method

The method of least squares was applied to the Panama Canal cargo tonnage data for the period 1947–1969. The 1969 data is the annual rate based on the first 6 months record. The least squares method establishes the equation of a curve such that the sum of the squares of the deviations of the data points from the curve is a minimum. This curve is the "best fitting curve." A straight line having this characteristic is called the least square line. A parabola having this property is the least square parabola.

A computer was used for the actual calculations. The middle year of the time period examined, 1958, was designated as zero. The units of the abscissa were one year, plus and minus from the zero point. This "x" scale removes the arbitrary magnitude of the calendar year so that the sum of the "x's" is zero. The ordinate was the logarithm of the cargo tonnage for each year. The Log Y, where Y = cargo tons, was used because the growth of the tonnage appears to approximate an exponential function. The logarithm of an exponential function is a straight line, and the least squares method can be applied most usefully to approximately linear data.

Three possible curves were fitted to the data:

Degree of Curvature	Equation	Curve
1	$\text{Log } Y = a_0+a_1x$	Straight Line
2	$\text{Log } Y = a_0+a_1x+a_2x^2$	Parabola or Quadratic
3	$\text{Log } Y = a_0+a_1x+a_2x^2+a_3x^3$	Cubic

The output of the program printed the coefficients in the above equations, the actual tonnage, the estimated tonnage (i.e., the tons determined by the equation of the curve), and the annual growth rate. The sum of the squares of the residuals (deviations) was indicated. The curve with the smallest sum was the "best fit." The growth rates were computed based on the estimated tons. Plots of the growth rates result in a constant **rate** of growth for the first degree line, a constant **change** of **rate** of growth for the second degree curve, and a quadratic curve for the rate of growth for the third degree curve.

Results

Total Cargo Tonnage

Total cargo tonnage has been increasing at an average annual growth rate of approximately 6.5 per cent. The third degree curve, which gave the best fit, showed an increasing growth rate at the end points of the time period, reflecting the effect of hostilities in Southeast Asia and continued Japanese economic expansion for the most recent years.

Commercial Cargo Tonnage

This tonnage has been increasing at a rate commensurate with that of the total cargo tonnage. Growth rate curves of the first, second, and third degree all very closely fit the observed data. The first degree curve indicated an average annual growth rate of 6.7 per

cent. The second and third degree curves indicated growth rates varying from 10.9% to 5.7% with extrapolation to succeeding years giving widely varying results.

Tanker Cargo Tonnage

The data points are somewhat more scattered in the early years, but the growth rate trend is clearly declining, with an actual decrease in tons recorded in 1968.

Total Cargo Less Tanker Cargo Tonnage

To examine the effect on the total cargo tonnage by the declining rate of growth of tanker traffic, the tanker tonnage was subtracted from the total and the least squares method applied to the remainder. As expected, total cargo tonnage showed a more rapid growth in recent years after subtracting the declining tanker trade.

Total Commercial Cargo Less Tanker Cargo Tonnage

The growth rate of the commercial traffic less the tanker cargo tons was examined. Again, the remainder of the tonnage showed a higher growth rate in later years after deduction of the declining tanker traffic.

Role of Trade to and from Japan

In 1969, trade with Japan amounted to 40% of Commercial Ocean Cargo tonnage. The growth of this trade was examined by dividing Commercial Ocean Cargo into two categories, "To and From Japan," and "All Other." The Japan traffic has shown a more rapid growth than the remainder of the commercial traffic. The rate of growth of the Japan traffic appears to be declining, although the percentage of the total is increasing rapidly. The rate of growth of the Commercial Traffic less Japan is low, due to the declining tanker component.

U.S. Intercoastal

U.S. intercoastal tonnage has demonstrated a negative growth rate (i.e., a declining tonnage).

U.S. to Foreign

This component of Commercial Ocean Traffic has shown an increasing growth rate in recent years, largely because of the previously identified increasing trade to Japan from the U.S. East Coast.

Foreign to U.S.

The growth rate of the U.S. import trade within the Commercial Ocean Traffic appears to be declining.

Foreign to Foreign

The Japan trade holds a less prominent position in the Foreign to Foreign category than in the U.S. to Foreign.

Conclusions

The results of this analysis do not appear to point to a particular trend which is a best predictor for projection of future canal traffic. The analysis does provide some useful insight and guidelines for establishment of trend projections. As is to be expected, examination of various components of the total results in the finding of some increasing trends and others decreasing. One major increasing growth component was identified–Japan trade. U.S. Government traffic fell in this category through 1968. However, in 1969 it experienced an absolute decline owing to the scaling down of hostilities in Southeast Asia. The tanker tonnage component appears to be declining.

The large increasing rates of growth indicated by the experience of recent years cannot be expected to continue. Even a continuation of a constant rate of growth of approximately 6.5 per cent leads to cargo tonnages of such magnitude in future years that such projections lose their value for determination of canal capacity requirements and anticipated revenues. If it is assumed that the tanker trade will continue to decrease or at best remain constant, that the scaling down of the Vietnam War will continue to result in decreasing U.S. Government traffic, and that the growth of Japan trade will diminish, then a declining growth rate is a reasonable projection. The rate of such decline will be determined by the actual performance and timing of the foregoing trends plus any growth effects from other trade routes and commodities.

Appendix 3

ISTHMIAN CANAL POTENTIAL TONNAGE FORECAST

Introduction and Summary

This Appendix presents the results of an economic analysis that develops an estimate of potential tonnage demand for commercial ocean traffic through an Isthmian interoceanic canal. The study examines the historical relationship between time series growth of commercial tonnage in the Panama Canal traffic to several combinations of independent variables to establish an acceptable correlation for a mathematical equation that serves as a forecasting device.

Total commercial ocean traffic is expected to develop to about 338 to 409 million long tons of cargo by the year 2000 reflecting a downward shift in annual growth to about half that of the post-World War II experience. Forecast results are treated in detail in the "Conclusion" section. This estimate of potential cargo tonnage results from computations related to Tonnage Series 4, which appears in Table A3-3 and is reflected in Tonnage Series 4-III in Figure A3-1.

Prefatory Comment

The quality of any forecast depends on an understanding of the factors of causality that operate to expand and constrain growth. The history of past Panama Canal forecasts of traffic growth is replete with attempts to link tonnage generation to assumed independent variables; results have been generally inadequate.

The classical approach utilizes a technique of commodity analysis termed disaggregation; here, the growth-maturation-stagnation cycles of commodities are employed to develop a total of commodity tonnage through the Canal. Subsequent analysis has shown that the influence of new commodity development not accounted for in disaggregation is increasingly important in extended forecast years because existing commodity growth generates proportionately less tonnage as it achieves the maturity phase of its cycle.

The obverse of this approach, called aggregation, involves the investigation of possible relationships in macroeconomic variables that exhibit a statistically measurable link that can be projected in the future (in an attempt to include the implications of enduring structural characteristics that dominate the economy in the long run). Temporary changes resulting from military emergencies, weather cycles and agriculture, business speculation and politics can have sharp repercussions in the short run, but tend to wash out over an extended time frame.

Aggregation, therefore, is not so much a forecast as a projection–of past enduring relationships into the future. The quality of such a projection is dependent on the depth of understanding of the relationship of the variables in the dynamics of the aggregation.

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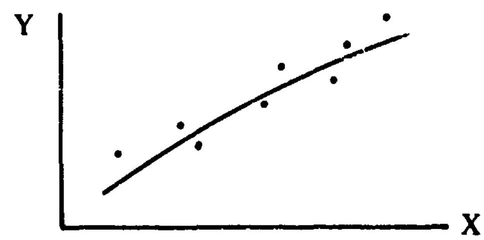
The normal method employed to manipulate data in the aggregative technique is statistical regression analysis. This measures the change in one variable against the change in another to test the degree of correlation; the statistical validity is measured by the correlation coefficient.[1]

The reader unfamiliar with such work may visualize this concept by the following diagram:



where y is the dependent variable, and x is the independent variable; a curve passed through the plot of the data points minimizes the distance between the points; the correlation coefficient expresses the degree of fit of the curve.

Logically meaningful relationships, however, can only be proved empirically, i.e., in common sense observation of real world events. It is theoretically possible to statistically "explain" relationships between variables that have no logical link so long as their rates of growth are accidentally harmonized. More importantly, this can occur with partially related variables; good judgment, therefore, is necessary in the selection of inputs for this regression technique.

The Investigation

The aggregation employed in this forecast is regional. Aggregation at the world level would omit important developments in regional economic evolution; aggregation at the national level would yield time series data characterized by perturbations unsuitable for regression work.

Fifteen regions of economic activity were specified which aggregate the total of nations that produce all Panama commercial ocean tonnage. Time series data from 1950 to 1967 were developed for each region consisting of (1) the regional product, (2) the per capita product, and (3) tonnage exports through the Canal. Three scenarios were considered to be of interest.

(1) Each region (considered as an origin) was related to each regional destination utilizing the regional product and the per capita product as the independent variables; this approach yielded 112 models.

(2) Each region (considered as an origin) was related to each regional destination utilizing the regional products of both as the independent variables; this approach yielded 112 models.

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[1] The correlation coefficient is an indicator that determines how well the regression line fits the observed data.

(3) Each region (considered as an origin) was related to all regional destinations utilizing the regional product of the origin as the independent variable; this approach yielded 15 models.

The first study considered alternative (1). Regression analysis[1] was performed and 112 models were obtained with four independent variables; the models, in most cases, were inadequate. The second study was identical to the first, except that two independent variables were used. Although there appeared some improvement in the correlation coefficients over the first, these 112 models were still inadequate. The third study considered alternative (3) with one independent variable. Thirteen models had correlation coefficients over .8 while two models (Asia Minor–Middle East and West Coast USA) were inadequate.

A linear function (or straight line curve) was derived which exhibited a high correlation coefficient, i.e., four of which are over .9 and the remainder (excepting Asia Minor–Middle East and West Coast USA) over 0.80. The Asia Minor–Middle East series was recomputed utilizing a shortened time series that omits perturbations apparently resulting from the general economic dislocation arising from the Suez situation. The West Coast USA series could undoubtedly be improved by increasing the complexity of the equation, but such an approach would conflict with the logic of the forecast and would increase the likelihood of error in estimating the growth of the independent variables. Moreover, the observation of such a preponderance of valid statistical relationships derived from a single independent variable is significant.

The resulting equations provide a mathematical forecasting device that allows the analyst to vary the independent variable (i.e., the regional product) and to therefore derive a new dependent variable (i.e., canal tonnage generated).

Table A3-1 presents the linear form and correlation coefficients. Tables A3-13 through A3-42 present the historical data.

The regional product of each of the 15 economic "cells" was similarly subjected to regression analysis to derive a forecast of regional product for each of the years from 1970 to 2000. In this case, the y-axis is occupied by the dependent variable, regional product, and the x-axis by the independent variable, "time." Introduction of a new "time"... or year yields a forecast of regional product.

The results exhibit high indexes of determination (which is a variant of the correlation coefficient) in all six curve-types. The results of the best three fits were utilized as input coefficients to develop alternate levels of tonnages. Tables A3-2 and A3-3 and Figure A3-1

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[1] A set of data points given in cartesian coordinates was fitted to six different curve types. The regression analysis computes the coefficients A and B for the best fit in each case and gives the index and F-ratio for each fit enabling the user to compare the fit of his points to each curve type. The curves fitted are expressed geometrically as follows:

1. $Y = A + Bx$
2. $Y = Ax^B$
3. $Y = Ae^{Bx}$
4. $Y = A + B/x$
5. $Y = 1/(A + Bx)$
6. $Y = x/(A + Bx)$

the letter "e" stands for the base of the natural logarithm, 2.718... For a more complete reference to mathematical formulation, see: *Statistics in Research*, 2nd Edition, by Bernard Ostle, Iowa State University Press, 1963, Chapter 8.

TABLE A3-1

RESULTS OF THE THIRD STUDY

(Alternative (3): one independent variable, regional product; one dependent variable, canal tonnage)

Origin	Model Y=A + Bx	Correlation Coefficient
East Coast USA	B=8.28 A=-23055	.976
East Coast Canada	B=3.8 A=532	.849
East Coast Central America	B=4.5 A=-517	.826
West Indies	B=82.0 A=-1188	.378
Europe	B=.59 A=779	.856
East Coast South America	B=29.6 A=-8439	.984
Asia Minor – Middle East	B=-3.8 A=238	.779
Africa	B=1.09 A=-250	.890
West Coast USA	B=-.56 A=6917	.115
West Coast Canada	B=28. A=1351	.855
West Coast Central America	B=6.5 A=-272	.917
West Coast South America	B=87.6 A=-153	.811
Oceania	B=8.1 A=233	.872
Japan	B=4.9 A=-1273	.922
Asia (less Japan)	B=6.4 A=439	.881

TABLE A3-2

CARGO TONNAGE SERIES 1, 2 & 3

Fiscal Year	Number 1[1] Cargo (000 Long Tons)	Number 1[1] Annual Pct. Increase	Number 2[2] Cargo (000 Long Tons)	Number 2[2] Annual Pct. Increase	Number 3[3] Cargo (000 Long Tons)	Number 3[3] Annual Pct. Increase
1968	84625.5		72264.7		89360.9	
1969	87883.0	3.8	73570.9	1.8	94368.1	5.6
1970	91140.6	3.7	74831.1	1.7	99616.7	5.6
1971	94398.1	3.6	76049.0	1.6	105120.2	5.5
1972	97655.7	3.5	77228.0	1.6	110892.7	5.5
1973	100913.2	3.3	78370.8	1.5	116949.4	5.5
1974	104170.8	3.2	79480.2	1.4	123306.3	5.4
1975	107428.3	3.1	80558.2	1.4	129980.7	5.4
1976	110685.8	3.0	81607.1	1.3	136990.7	5.4
1977	113943.4	2.9	82628.6	1.3	144356.0	5.4
1973	117200.9	2.9	83624.5	1.2	152[illegible]97.4	5.4
1979	120458.5	2.8	84596.2	1.2	160237.1	5.4
1980	123716.0	2.7	85545.0	1.1	168799.0	5.3
1981	126973.6	2.6	86472.4	1.1	177808.5	5.3
1982	130231.1	2.6	87379.3	1.0	187292.9	5.3
1983	133488.6	2.5	88266.9	1.0	197281.3	5.3
1984	136746.2	2.4	89136.1	1.0	207804.9	5.3
1985	140003.7	2.4	89987.9	1.0	218897.2	5.3
1986	143261.3	2.3	90823.0	.9	230594.2	5.3
1987	146518.8	2.3	91642.3	.9	242934.2	5.4
1988	149776.4	2.2	92446.4	.9	255958.7	5.4
1989	153033.9	2.2	93236.0	.9	269712.0	5.4
1990	156291.4	2.1	94011.7	.8	284241.9	5.4

TABLE A3-2

CARGO TONNAGE SERIES 1, 2, & 3 (Cont'd.)

Fiscal Year	Number 1[1] Cargo (000 Long Tons)	Number 1[1] Annual Pct. Increase	Number 2[2] Cargo (000 Long Tons)	Number 2[2] Annual Pct. Increase	Number 3[3] Cargo (000 Long Tons)	Number 3[3] Annual Pct. Increase
1991	159549.0	2.1	94774.1	.8	299599.5	5.4
1992	162806.5	2.0	95523.8	.8	315840.0	5.4
1993	166064.1	2.0	96261.2	.8	333022.8	5.4
1994	169231.6	2.0	96986.9	.8	351211.8	5.5
1995	172579.2	1.9	97701.3	.7	370475.8	5.5
1996	175836.7	1.9	98404.7	.7	390889.0	5.5
1997	179094.2	1.9	99097.6	.7	412531.3	5.5
1998	182351.8	1.8	99780.4	.7	435489.0	5.6
1999	185609.3	1.8	100453.4	.7	459855.3	5.6
2000	188866.9	1.8	101117.0	.7	485730.5	5.6

[1] Curve type $Y = A + Bx$ used to forecast regional product.

[2] Curve type $Y = Ax^B$ used to forecast regional product.

[3] Curve type $Y = Ae^{Bx}$ used to forecast regional product.

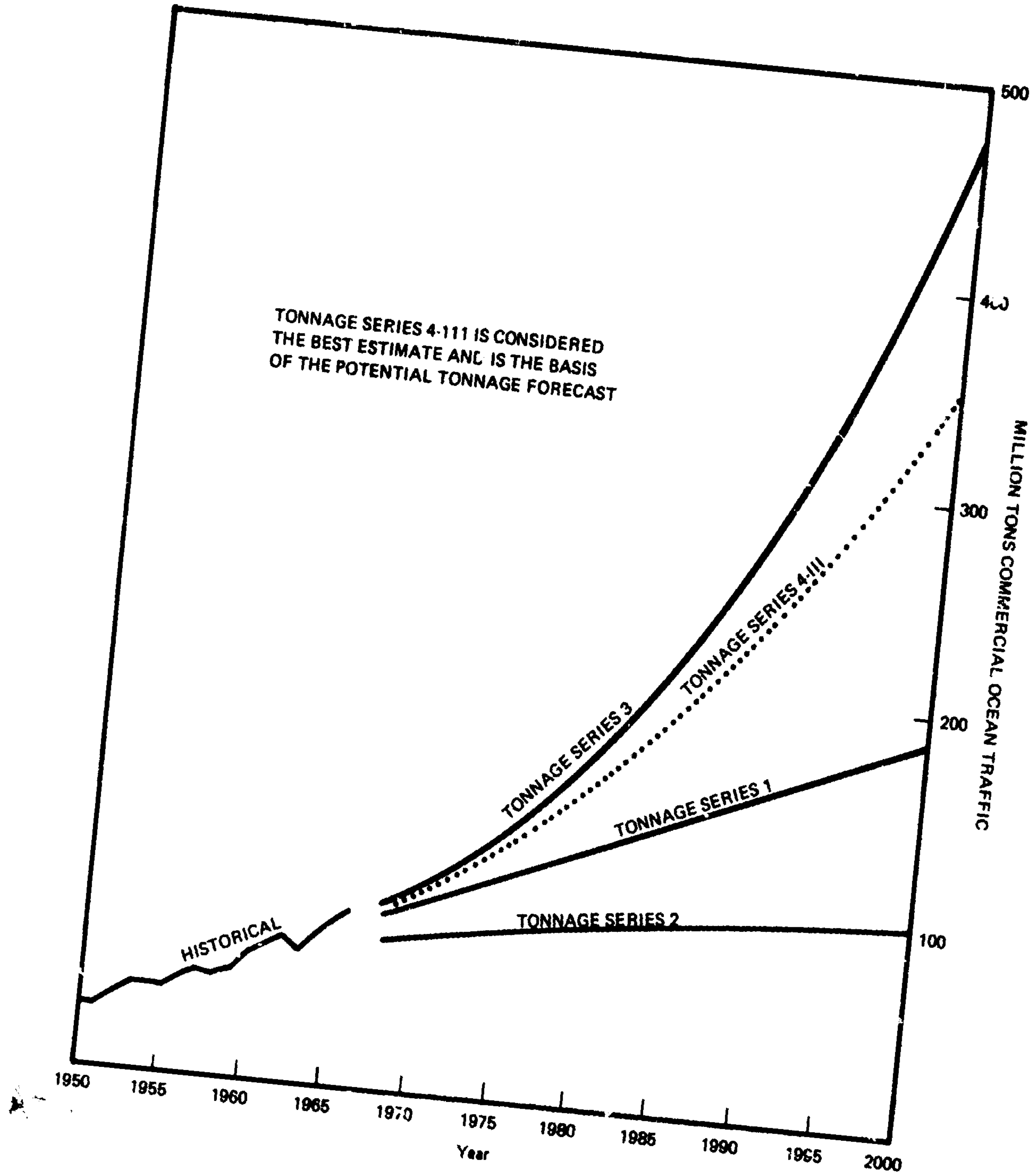
TABLE A3-3
CARGO TONNAGE SERIES 4
(000 Long Tons)

Fiscal Year	I[1]	II[2]	III[2,3]	IV[2]	V[2]
		(9.5-6.0)	(9.5-5.0)	(9.5-4.0)	(9.5-3.0)
1968	87793	88019	88019	88019	88019
1969	92285	92531	92531	92521	92516
1970	96952	97205	97196	97186	97166
1971	101804	102051	102036	102017	101973
1972	106850	107084	107050	107005	106942
1973	112103	112304	112245	112171	112078
1974	117574	117722	117639	117521	117384
1975	123277	123349	123226	123059	122863
1976	129225	129196	129019	128799	128524
1977	135433	135268	135048	134734	134377
1978	141917	141569	141280	140883	140462
1979	148695	148119	147752	147247	146669
1980	155784	154927	154456	153829	153119
1981	163204	162008	161420	160641	159778
1982	170978	169367	168637	167686	166662
1983	179127	177026	176125	174973	173758
1984	187677	184990	183887	182545	181099
1985	196653	193246	191943	190370	188679
1986	206085	201840	200282	198430	196504
1987	216004	210776	208944	206793	204583
1988	226441	220069	217928	215434	212915
1989	237436	229736	227257	224390	221563
1990	249023	239786	236909	233636	230456
1991	261247	250236	246929	243219	239662
1992	274152	261109	257321	253137	249158
1993	287787	272411	268104	263581	258980
1994	302206	284162	279252	273990	269114
1995	317446	296380	290819	284973	279593
1996	333628	309129	302813	296345	290441
1997	350761	322384	315245	308115	301628
1998	368936	335273	328140	320270	313205
1999	388233	350487	341510	332852	325184
2000	408738	365372	355367	345875	337575

[1] Straight application of best coefficients.

[2] II thru V vary the Japan product growth rate as shown. However, the Japan growth rate is treated qualitatively resulting from separate analysis. Additional Note: All tonnages employ curve (3) coefficients except West Indies, East Coast South America which are (1).

[3] Used as the potential tonnage forecast of this Study.



FORECAST OF ISTHMIAN CANAL TRAFFIC

FIGURE A3-1

present the results. The indexes and equation coefficients for these three best fits are listed in Table A3-66. It should be noted that in each tonnage forecast depicted in the results, the forecast for Fiscal Years 1968 and 1969 is lower than the actual Panama Canal commercial experience for these years (i.e., 96.5 million tons in 1968 and 101.4 million tons in 1969). The deviation of the forecast tonnage from the recent historical experience can be understood by the fact that it (the forecast tonnage) represents, in fact, a curve which best fits the entire historical series. Therefore, while the forecast does not achieve a best approximation of the most recent years, it represents a judgment based on the entire historical experiences since 1950. Consequently, one can conclude that the middle range years of the forecast period up to the year 2000 (i.e., 1980-1990) would have the the greatest probability of approximating the forecast in the same manner that the historical curve fits all the data points.

The statistical measure of the tonnage-per-regional product growth for the 18-year historical experience in each region is translated into new tonnage levels by introduction of new coefficients in the linear equation, derived from regression of the regional product series.

The Economic Assumptions

The predictive device is only as good as the assumption of continuity of this relationship. This is really an average of different relationships through the observed period although the high correlation in the linear form gives confidence in minimal deviation from the average line. Nevertheless, evidence exists to suggest that the tonnage-per-regional product shifts over time as economic maturation occurs.[1] This evolution warps the forecast in an overstatement of tonnage (as almost all regions' per capita levels are rising) insofar as the rate of change downward accelerates above that experienced in the past.

The historical data series was selected from a period of world commerce unaffected by world war; a necessary implication of this forecast is the assumption of no extraordinary political–economic dislocation. Also, because the historical time series provides the basis from which the future is extrapolated, marked changes in past relationships in trade patterns and economic growth will distort the forecast. the potential development of oil deposits in Northern Alaska is one example that could alter routes to refinery and market. Another is the future economic growth of Japan.

Japanese Economic Growth

Japan's economy set records for sustained economic growth through the 18-year period under consideration; at the same time, this country's proportional contribution to Canal commercial tonnage increased markedly (see Tables A3-7 through A3-10). An analysis of these growth rates suggested adoption of a more empirically-oriented approach to the forecasts of these series.

Japan's GNP, at the end of Fiscal Year 1971, is expected to total $200 billion, and Japan will have consolidated its position as the third largest economy in the world. Over the

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[1] A growth in regional product generates an increase in tonnage exports that transit a canal, but in a proportionately smaller ratio as the per capita product rises. This may be explained by the implications of such an advance in industrial maturity; vertical and horizontal domestic economic integration encourages internal satisfaction of economic industries which characteristically promote dense-weight tonnage exports.

past 10-year period, Japan has averaged an annual 14 percent increase in nominal GNP (about 10 percent in real terms). Table A3-4 contains a summary of economic indicators pertaining to Japan.

The main thrust of Japanese economic progress during the past decade has been achieved through intensive domestic investment (particularly in plant and equipment)[1] to exploit a rapidly expanding domestic market created through increases in real income and low rate of population growth. Although the pattern is expected to continue for the short range, eventual diminution in the surplus rural labor supply is expected to cause inflationary pressures. Additionally, the long-range prospects for real product growth must consider the critical limitation of land.

The historic advantages of technological advance (in an economic area characterized by poverty and low levels of mechanization, low labor costs, and opportunities for exploitation of markets such as the European Economic Community, European Free Trade Association, and the U.S.) will probably not continue to propel the Japanese economic development along past lines of growth.

The forecast of Japan's economic development (and resulting implicit export tonnage through a canal) contained in this study departs from the recent high levels of sustained performance, and is instead reflective of such aforementioned institutional and economic constraints expressed in performance levels exhibited by other mature island nations, e.g., Great Britain. For projections of Japan product growth and cargo tonnage growth, see Tables A3-5 and A3-6.

Mainland China

The influence of Communist China on expansion of Isthmian canal tonnage depends on the evolution of new political accommodation with the United States and on internal economic development with respect to ability to export desired commodities in the competitive market.

Most Government observers cautiously predict a thaw in our political relationship with Mainland China over the next decade. Such a development would establish a framework within which could exist a potential for bilateral trade. The economic realities of world trade, however, could work to restrain development of tonnage trade with the United States which remains the prime generator of Isthmian canal trade from China.

Little is known about the internal developments of China's institutional evolution and revolution; China watchers, nevertheless, conclude that ideological reforms attendant to Chairman Mao's "Great Leap Forward" caused serious damage to China's economic development in an attempt to supplant agriculture by heavy industry development as the prime goal. These priorities were reversed again in the early 60's but the steady economic development which followed during the period 1962-1966 was again set back by Mao Tse-tung's "Cultural Revolution" 1966-1969. A long range forecast of China's world trade potential is dependent on fundamental idealogical-economic trends which appear to be reemphasizing agricultural development. Such a program would reinforce the present

[1] Private investment in plant and equipment increased as a percentage of GNP from 22.0 to 31.0 over the period 1966-69; the level is about twice that of the United States. Foreign trade as a percentage of Japan's GNP is only about 20 percent. This is less than half the level sustained by many advanced European nations.

dependence of China on Japan and Western Europe for supply of sophisticated industrial equipment and would severely limit China's ability to competitively enter the world trade market with products attractive to the United States. American raw material import requirements generally are satisfied by existing sources and exports are somewhat higher priced than European counterparts.

Economic Forecast

A realignment of China's economic priorities that emphasizes agricultural development will probably result in a slow but steady rate of growth in gross national product; 3 per cent annually has been chosen. However, continuation of a big population problem will probably hold down the rate of growth in per capita GNP to about 1 per cent annually. The Canal Tonnage/GNP ratio for China equalled 1.823 in the highly disruptive year of 1950; it has since declined to .135 in 1967, principally by virtue of our economic boycott. Given performances of the Canal/GNP ratio for other similarly placed regions, it is reasonable to predicate a rise in this ratio to at least 5.0 over the next thirty years assuming reestablishment of good relations. Results are summarized in Table A3-11. China's Isthmian canal tonnage would, therefore, increase from 11.8 thousand tons in 1967 to over 1 million tons by year 2000 based on a total GNP of $241.9 billion, a per capita BNP of $139.6 and a Tonnage/GNP ratio of 4.45.

Conclusion

Four series of cargo tonnage forecasts are presented.

The first three reflect the growth rates of tonnage resulting from introduction of product coefficients developed by each of the three curve types. (Table A3-2).

The fourth reflects the growth rates of tonnage resulting from introduction of product coefficients of the three curve types that exhibit the best correlation coefficient (Table A3-3).

Five variants on this fourth series are presented: 1/straight application of best correlation coefficients; 2/alteration of the Japan product forecast from the best curve fit of 9.5 per cent annually on an exponential line to 9.5 per cent annually declining to 6.0 per cent; 3/alteration of the Japan product forecast to 9.5 per cent annually declining to 5.0 per cent; 4/alteration of the Japan product forecast to 9.5 per cent annually declining to 4.0 per cent; 5/alteration of the Japan product forecast to 9.5 per cent annually declining to 3.0 per cent. For purposes of this forecast it was assumed that the product growth rate of 9.5 per cent declining uniformly on an annual basis to 5.0% by the year 2000 was a reasonable estimate of future Japan product growth.

An Extended Forecast

Little can be said about a forecast of Isthmian canal tonnage beyond the Twentieth Century. The statistical forecasting device used in this Study has a limitation analogous to that of a camera's focal length–imprecise in the very short and very long ranges. Statistical manipulation of economic data gives way to philosophical speculation in such extreme cases.

From year 2000 to 2040, a curve of uniformly declining rate (or slope) was constructed such that at year 2040 the rate of increase is zero per cent. The "bending down" of the rate

of growth in this period resulted basically from inability to forecast world trends from 30 to 70 years into the future. The curve diminishing to zero per cent of growth at 2040 was selected as a conservative growth estimate. the predicted tonnages are listed in Table A3-12.

The Data

No single source exists for a comprehensive GNP series by nation and sub-group over the period required. Considerable data combination and manipulation was required to develop a statistical series[1] expressed in constant 1967 U.S. dollars; four documents, however, provided the bulk of the material:

1) *Gross National Product: Growth Rates and Trend Data by Region and Country,* April 1969, A.I.D., U.S. Department of State.
2) *Finance and Development* quarterly No. 1, 1969, the I.M.F. and World Bank Group.
3) *Statistical Yearbook,* 1967 . . .
4) *Yearbook of National Accounts,* 1967, both of the United Nations.

Cargo tonnage data were provided by the Panama Canal Company. Population information came from a variety of sources with special reference to the Commerce Department's Bureau of the Census, Foreign Demographic Division. Information on growth rates in Communist China relates to various State Department publications and two Senate documents entitled *Mainland China in the World Economy,* Hearings, 1967 and Report, 1967.

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[1] East Coast USA: all states excepting Pacific and Pacific Northwest (GNP was divided by apportionment of the 1967 estimated population ratio); West Coast USA: Pacific and Pacific Northwest states (per capita product is assumed identical for each coast); East Coast Canada: excludes British Columbia, Alberta, Saskatchewan, Manitoba (apportionment of GNP was based on the estimated 1966 population); West Coast Canada: includes the above mentioned provinces; East Coast Central America: Mexico, Panama, Costa Rica, Guatemala, Honduras, Nicaragua; West Coast Central America is identical; West Indies: Puerto Rico, Cuba, Haiti, Dominican Republic, Jamaica, Trinidad/Tobago, Barbados, Bahamas, Netherlands Antilles; Europe: all OECD countries; East Coast South America: Argentina, Brazil, Colombia, Venezuela; Middle East: Israel, Lebanon, Syria, Cyprus; Africa: all nations on the continent; West Coast South America: Chile, Colombia, Ecuador, Peru; Asia (less Japan): Indonesia, Taiwan, Hong Kong, Philippines and both Koreas; Oceania: Australia and New Zealand; Japan: Japan.

TABLE A3-4
JAPAN
ECONOMIC INDICATORS

Item	Unit	1966	1967	1968	1969 (Estimate)	1970 (Forecast)
I. Income, Investment, Employment						
GNP (Current prices)	$Bil.	102	120	142	176	200
Growth Rate						
(nominal)	%	15.0	18.0	19.0	19.0	16.0
(real)	%	10.0	13.0	14.0	14.0	12.0
Population*	Mil.	99	100	101	102	103
Per Capita GNP	$	1,029	1,198	1,399	1,725	1,941
Labor Force	Mil.	49	49	50	52	–
Unemployment rate	%	1.3	1.3	1.2	1.1	–
Private Investment as % of GNP	%	22.0	25.0	26.0	31.0	31.0
Increase in New Plant and Equipment Investment	%	21.0	27.0	22.0	26.0	17.0
II. Production*						
Mining and Manufacturing	%	13.2	19.4	16.9	15.5	--
Rice	Mil. MT	12.7	14.5	14.5	14.0	–
Crude Steel	Mil. MT	47.8	62.2	66.9	82.1	–
Ships	Mil. GT	6.4	8.0	8.4	–	–
Passenger Cars	Mil. Units	0.9	1.4	2.2	2.6	–
Synthetic Fabrics	MT (1000's)	460	578	689	–	–

TABLE A3-4
JAPAN
ECONOMIC INDICATORS (Cont'd)

Item	Unit	1966	1967	1968	1969 (Estimate)	1970 (Forecast)
III. Money and Prices						
Public Debt	$ Bil.	8.0	10.8	13.6	13.1	–
Consumer Price Rise*	%	5.1	4.0	5.3	5.2	–
Wholesale Price Rise*	%	2.4	0.2	0.8	2.2	–
Wages – Nominal*	%	10.3	12.1	14.2	14.9	–
National Budget (General Acct.)	$ Bil.	12.4	14.4	16.4	18.7	22.1
Gold and Foreign Exchange Reserve	$ Mil.	2,074	2,005	2,891	3,496	–
Overall BOP Position*	$ Mil.	+355	-571	+1,102	+2,283	–

*Calendar Year; all others Fiscal Year.

TABLE A3-5
JAPAN: PROJECTED PRODUCT GROWTH RATES
(Billions of Dollars)

Fiscal Year	9.5%* to 6.0%	9.5%* to 5.0%	9.5%* to 4.0%	9.5%* to 3.0%
1968	121.4 9.5	121.4 9.5	121.4 9.5	121.4 9.5
1969	132.9 9.4	132.9 9.4	132.7 9.3	132.6 9.2
1970	145.2 9.3	145.0 9.2	144.8 9.1	144.4 8.9
1971	158.4 9.1	158.1 9.0	157.7 8.9	156.8 8.6
1972	172.7 9.0	172.0 8.8	171.1 8.5	169.8 8.3
1973	188.0 8.9	186.8 8.6	185.3 8.3	183.4 8.0
1974	204.4 8.7	202.7 8.5	200.3 8.1	197.5 7.7
1975	222.0 8.6	219.5 8.3	216.1 7.9	212.1 7.4
1976	240.9 8.5	237.3 8.1	232.8 7.7	227.2 7.1
1977	261.1 8.4	256.6 8.0	250.2 7.5	242.9 6.9
1978	282.5 8.2	276.6 7.8	268.5 7.3	259.1 6.7
1979	305.4 8.1	297.9 7.7	287.6 7.1	275.8 6.4
1980	329.8 8.0	320.2 7.5	307.4 6.9	292.9 6.2
1981	355.9 7.9	343.9 7.4	328.0 6.7	310.4 6.0
1982	383.6 7.8	368.7 7.2	349.3 6.5	328.4 5.8
1983	413.2 7.7	394.8 7.1	371.3 6.3	346.5 5.5
1984	444.6 7.6	422.1 6.9	394.7 6.2	365.2 5.4
1985	477.4 7.4	450.8 6.8	418.4 6.0	384.2 5.2
1986	512.3 7.3	480.5 6.6	442.7 5.8	403.4 5.0
1987	549.2 7.2	511.8 6.5	467.9 5.7	422.8 4.8
1988	588.2 7.1	544.5 6.4	493.6 5.5	442.2 4.6
1989	629.4 7.0	578.8 6.3	520.3 5.4	462.6 4.5
1990	672.8 6.9	614.1 6.1	547.3 5.2	482.4 4.3
1991	718.5 6.8	651.0 6.0	575.3 5.1	502.7 4.2
1992	766.7 6.7	689.4 5.9	604.0 5.0	522.8 4.0
1993	817.3 6.6	729.4 5.8	633.0 4.8	543.2 3.9
1994	870.4 6.5	770.2 5.6	662.8 4.7	563.3 3.7
1995	926.1 6.4	812.6 5.5	693.3 4.6	583.5 3.6
1996	985.4 6.4	856.5 5.4	724.5 4.5	604.0 3.5
1997	1047.5 6.3	901.8 5.3	756.3 4.4	623.9 3.3
1998	1112.4 6.2	948.7 5.2	788.1 4.2	643.9 3.2
1999	1180.3 6.1	997.1 5.1	820.4 4.1	663.9 3.1
2000	1251.1 6.0	1046.9 5.0	853.2 4.0	683.8 3.0

*Average annual increase based on alternate percentage assumptions.

TABLE A3-6

JAPAN: PROJECTION OF CARGO TONNAGE GROWTH BASED ON HISTORICAL RELATIONSHIP BETWEEN PRODUCT AND TONNAGE

(000 Long Tons)

Alternate Product Growth Rate Assumptions

Fiscal Year	I 9.5-6.0%	II[1] 9.5-5.0%	III 9.5-4.0%	IV 9.5-3.0%
1968	4675	4675	4675	4675
1969	5239	5239	5229	5224
1970	5841	5832	5822	5802
1971	6488	6473	6454	6410
1972	7189	7155	7110	7047
1973	7939	7880	7806	7713
1974	8742	8659	8541	8404
1975	9605	9482	9315	9119
1976	10531	10354	10134	9859
1977	11520	11300	10986	10629
1978	12569	12280	11883	11462
1979	13691	13324	12819	12241
1980	14887	14416	13789	13079
1981	16166	15578	14799	13936
1982	17523	16793	15842	14818
1983	18973	18072	16920	15705
1984	20512	19409	18067	16621
1985	22119	20816	19243	17552
1986	23829	22271	20419	18493
1987	25637	23805	21654	19444
1988	27548	25407	22913	20394
1989	29567	27088	24221	21394
1990	31694	28817	25544	22364
1991	33933	30626	26916	23359
1992	36295	32507	28323	24344
1993	38774	34467	29744	25343
1994	41376	36466	31204	26328
1995	44105	38544	32698	27318
1996	47011	40395	34227	28323
1997	50054	42915	35785	29298
1998	52346	45213	37343	30278
1999	56561	47584	38926	31258
2000	60030	50025	40533	32233

[1] Used in the forecast for tonnage originating in Japan.

TABLE A3-7

JAPAN: ECONOMIC INFLUENCE OF PANAMA CANAL TRAFFIC

Fiscal Year	Total Commercial Ocean Cargo (000 Long Tons)	Annual Percent Change	Commercial Ocean Cargo to and from Japan (000 Long Tons)	Annual Percent Change	Japan-Percent Total Commercial Ocean Cargo
1950	28872	0.00	2210	0.00	7.65
1951	30073	4.17	3021	36.70	10.05
1952	33611	11.75	4370	44.65	13.00
1953	30095	7.00	5683	30.05	15.74
1954	39095	8.63	6696	17.83	17.13
1955	40646	3.91	6140	-8.30	15.11
1956	45119	11.08	7217	17.54	16.00
1957	49702	10.15	10196	41.28	20.51
1958	48125	-3.24	8504	16.59	17.67
1959	51153	6.27	9081	6.79	17.75
1960	59258	15.96	12206	34.41	20.60
1961	63670	7.49	15332	25.61	24.08
1962	67525	6.08	17753	15.79	26.29
1963	62247	-7.93	15368	-13.43	24.69
1964	70550	13.48	19812	28.92	28.08
1965	76573	8.51	21358	7.80	27.89
1966	81704	6.73	24470	14.57	29,95
1967	86193	5.49	28863	17.95	33.49

TABLE A3-8

JAPAN: ECONOMIC INFLUENCE ON PANAMA CANAL TRAFFIC

Fiscal Year	Commercial Ocean Cargo Change (000 Long Tons)	Japan Cargo Change (000 Long Tons)	Percent Change Japan/Total Commercial	Total Commercial Cargo Change Less Japan	Percent Change Total Commercial Less Japan
1950	0	0	0.00	0	0.00
1951	1201	811	67.41	390	32.59
1952	3538	1349	38.17	2189	61.83
1953	2484	1313	52.86	1171	47.14
1954	3000	1013	33.77	1987	66.23
1955	1551	-556	-35.85	2107	135.85
1956	4473	1077	24.08	3396	75.92
1957	4683	2979	63.61	1704	36.39
1958	-1577	-1682	106.65	105	-6.65
1959	3028	577	19.05	2451	80.95
1960	8105	3125	38.56	4980	61.34
1961	4412	3126	70.85	1286	20.15
1962	3855	2421	62.80	1434	37.20
1963	-5278	-2385	45.19	-2893	54.81
1964	8303	4444	53.52	3859	46.48
1965	6023	1546	25.67	4477	74.33
1966	5131	3112	60.65	2019	39.35
1967	4489	4393	97.86	96	2.14

TABLE A3-9

JAPAN: ECONOMIC INFLUENCE ON PANAMA CANAL TRAFFIC

Fiscal Year	Total Commercial Ocean Cargo Pacific to Atlantic (000 Long Tons)	Percent Change	Commercial Ocean Cargo from Japan (000 Long Tons)	Percent Change	Japan Percent Pacific to Atlantic Cargo
1950	19388	0.00	218	0.00	1.12
1951	18941	-2.30	335	53.67	1.77
1952	18482	-2.44	340	1.49	1.84
1953	18766	1.54	461	35.59	2.46
1954	20717	10.40	516	11.93	2.49
1955	22227	7.29	583	12.93	2.62
1956	23833	7.23	877	50.43	3.68
1957	24272	1.84	816	-.61	3.36
1958	25282	4.16	672	-17.65	2.66
1959	28707	13.55	1108	64.88	3.86
1960	31684	10.37	1217	9.84	3.84
1961	29222	-7.77	1129	-7.23	3.86
1962	29817	2.09	1250	10.72	4.19
1963	29161	-2.20	1750	40.00	6.00
1964	31649	8.53	2028	15.89	6.41
1965	33624	6.22	3452	70.22	10.27
1966	35032	4.23	4876	41.25	13.92
1967	32202	-8.09	4771	-2.15	14.82

TABLE A3-10

JAPAN: ECONOMIC INFLUENCE ON PANAMA CANAL TRAFFIC

Fiscal Year	Total Commercial Ocean Cargo Atlantic to Pacific (000 Long Tons)	Percent Change	Commercial Ocean Cargo to Japan (000 Long Tons)	Percent Change	Japan Percent Atlantic to Pacific Cargo
1950	9484	0.00	1992	0.00	21.0[illegible]
1951	11132	17.39	2686	34.84	24.1[illegible]
1952	15129	35.90	4030	50.04	26.64
1953	17329	14.55	5222	29.58	30.14
1954	18378	6.08	6180	18.35	33.62
1955	18419	.21	5557	-10.08	30.17
1956	21286	15.63	6340	14.[illegible]7	29.76
1957	25430	19.39	9380	47.[illegible]5	36.89
1958	22843	-10.16	7832	-16.50	34.28
1959	22446	-1.74	7973	1.80	35.52
1960	27574	22.84	10989	37.83	39.85
1961	34448	24.93	14203	29.25	41.23
1962	37708	9.46	16503	16.19	43.77
1963	33086	-12.47	13618	-17.48	41.26
1964	38901	17.86	17784	30.59	45.72
1965	42949	10.38	17906	.69	41.70
1966	46672	8.70	19594	9.43	41.98
1967	53991	15.68	24092	22.96	44.62

TABLE A3-11
FORECAST – MAINLAND CHINA

Fiscal Year	GNP Growth @ 3% (1967 U.S. billion $)	Per Capita GNP Growth @ 1% (1967 U.S. $)	Isthmian Canal Cargo (000 Long Tons)	Ratio[1] Tonnage/GNP (x 10^{-4})
1967	87.0	100.0	11.777	.135
1968	89.6	101.0	13.44	.150
1969	92.3	102.1	15.41	.167
1970	95.1	103.0	17.68	.186
1971	103.0	104.6	21.23	.206
1972	106.1	105.6	24.29	.229
1973	109.3	106.7	25.03	.255
1974	112.6	107.8	31.86	.283
1975	115.9	108.8	36.39	.314
1976	119.5	109.9	41.82	.350
1977	123.0	111.0	47.85	.389
1978	126.7	112.1	54.73	.432
1979	130.5	113.2	62.77	.481
1980	134.4	114.7	71.90	.535
1981	138.4	115.5	82.21	.594
1982	142.1	116.6	94.07	.662
1983	146.4	117.8	107.60	.735
1984	150.8	119.0	123.50	.819
1985	155.3	120.2	141.16	.909
1986	159.9	121.4	161.49	1.01
1987	164.8	122.6	184.57	1.12
1988	169.7	123.8	212.12	1.25
1989	174.8	125.1	242.97	1.39
1990	180.0	126.3	277.20	1.54

TABLE A3

FORECAST – MAINLAND CHINA (Cont'd.)

Fiscal Year	GNP Growth @ 3% (1967 U.S. billion $)	Per Capita GNP Growth @ 1% (1967 U.S. $)	Isthmian Canal Cargo (000 Long Tons)	Ratio Tonnage/GNP ($x\ 10^{-4}$)
1991	185.4	127.6	318.88	1.72
1992	191.0	128.9	364.81	1.91
1993	196.7	130.2	417.00	2.12
1994	202.6	131.5	476.11	2.35
1995	208.7	132.8	546.79	2.62
1996	214.9	134.1	625.35	2.91
1997	221.4	135.5	717.34	3.24
1998	228.0	136.8	820.80	3.60
1999	234.9	138.2	941.95	4.01
2000	241.9	139.6	1076.45	4.45

[1] Growth from .135 to 4.45 reflects an average annual increase of 11.2%.

TABLE A3-12

AN EXTENDED PROJECTION OF COMMERCIAL OCEAN CARGO TONNAGE FOR YEARS 2000 - 2040

Fiscal Year	Long Tons (Million)	Fiscal Year	Long Tons (Million)
2000	355.367	2021	653.075
2001	369.427	2022	665.001
2002	383.669	2023	676.470
2003	398.070	2024	687.450
2004	412 609	2025	697.912
2005	427.259	2026	707.824
2006	441.997	2027	717.159
2007	456.794	2028	725.890
2008	471.624	2029	733.990
2009	486.456	2030	741.437
2010	501.261	2031	748.206
2011	516.008	2032	754.279
2012	530.666	2033	759.635
2013	545.202	2034	764.259
2014	559.583	2035	768.136
2015	573.775	2036	771.253
2016	587.745	2037	773.600
2017	601.495	2038	775.170
2018	614.883	2039	775.956
2019	627.983	2040	775.956
2020	640.725		

HISTORICAL DATA

(Tables A3-13 through A3-42)

TABLE A3-13

EAST COAST USA

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Population (Millions)	Origin Cargo (000 Long Tons)
1950	$350.9	$2655	132.17	6284
1951	376.9	2816	133.84	6643
1952	387.5	2852	135.87	9230
1953	403.9	2932	137.76	10039
1954	399.6	2841	140.65	11283
1955	426.1	3004	141.84	11264
1956	432.5	3005	143.93	12201
1957	437.7	2994	146.19	15132
1958	431.0	2910	148.11	12761
1959	457.6	3046	150.23	12825
1960	467.9	3071	152.36	15893
1961	475.8	3078	154.58	19094
1962	505.7	3229	156.61	20836
1963	524.7	3310	158.52	17571
1964	553.4	3442	160.78	23090
1965	587.6	3612	162.68	24555
1966	624.3	3797	164.42	27124
1967	638.8	3847	166.05	31927

TABLE A3-14

EAST COAST CANADA

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Population (Millions)	Origin Cargo (000 Long Tons)
1950	$19.2	$1895	10.13	185
1951	20.4	1966	10.38	241
1952	22.3	2058	10.84	287
1953	22.9	2061	11.00	533
1954	22.6	1961	11.52	399
1955	24.5	2075	11.81	302
1956	26.6	2201	12.09	362
1957	26.6	2154	12.35	470
1958	26.9	2126	12.65	335
1959	27.8	2146	12.95	282
1960	28.9	2151	13.44	495
1961	29.2	2162	13.51	771
1962	31.2	2266	13.77	960
1963	32.8	2341	14.01	712
1964	34.9	2447	14.26	902
1965	36.8	2569	14.32	969
1966	38.9	2660	14.62	689
1967	40.6	2686	15.12	1043

TABLE A3-15

EAST COAST CENTRAL AMERICA

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Population (Millions)	Origin Cargo (000 Long Tons)
1950	$10.5	$300	35.00	193
1951	11.2	310	36.13	158
1952	11.7	315	37.14	212
1953	11.9	311	38.26	163
1954	12.9	327	39.45	53
1955	13.9	342	40.64	31
1956	14.8	352	42.05	60
1957	15.9	366	43.44	69
1958	16.7	372	44.89	60
1959	17.2	371	46.36	54
1960	18.5	385	48.05	137
1961	19.2	387	49.61	167
1962	20.2	394	51.27	239
1963	21.4	404	52.97	404
1964	23.4	[illegible]	54.80	563
1965	24.7	436	56.65	563
1966	26.5	451	58.76	833
1967	28.1	463	60.69	1077

TABLE A3-16

WEST INDIES

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Population (Millions)	Origin Cargo (000 Long Tons)
1950	$3.4	$230	14.78	1032
1951	3.6	238	15.13	1441
1952	3.9	249	15.66	2427
1953	4.1	259	15.83	3014
1954	4.4	268	16.42	2815
1955	4.8	266	16.78	2685
1956	5.2	306	16.99	2858
1957	5.7	321	17.76	3060
1958	5.8	321	18.07	3157
1959	6.3	335	18.81	3339
1960	6.5	344	18.90	3174
1961	6.9	357	19.33	5498
1962	7.0	353	19.83	6711
1963	7.2	350	20.57	4454
1964	7.6	364	20.88	4547
1965	8.1	376	21.54	5217
1966	8.3	374	22.19	5104
1967	8.7	391	22.25	6233

TABLE A3-17

EUROPE

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Population (Millions)	Origin Cargo (000 Long Tons)
1950	$258.5	$ 857	301.63	1599
1951	274.4	902	304.21	2293
1952	283.0	933	303.32	2486
1953	297.7	963	309.14	2274
1954	312.6	1002	311.98	2765
1955	331.7	1054	314.71	2881
1956	346.7	1094	316.91	3094
1957	361.0	1126	320.60	3762
1958	368.9	1140	323.60	3094
1959	386.0	1181	326.84	2934
1960	411.3	1246	330.10	3362
1961	432.7	1297	333.62	3538
1962	451.9	1338	337.74	3615
1963	472.4	1383	341.58	3363
1964	501.0	1450	345.52	3422
1965	521.9	1495	349.10	3488
1966	540.5	1533	352.58	3716
1967	555.9	1563	355.66	4368

TABLE A3-18

EAST COAST SOUTH AMERICA

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Population (Millions)	Origin Cargo (000 Long Tons)
1950	$27.1	$317	85.49	203
1951	28.5	323	88.24	298
1952	28.8	317	90.85	450
1953	30.5	327	93.27	827
1954	31.4	326	96.32	778
1955	34.6	349	99.14	1065
1956	35.6	349	102.01	2457
1957	37.9	360	105.28	2754
1958	40.1	373	107.51	3230
1959	41.5	375	110.67	2886
1960	44.2	389	113.62	4351
1961	46.7	400	116.75	5236
1962	48.2	401	120.20	5109
1963	48.5	393	123.41	6248
1964	51.2	404	126.73	6133
1965	54.0	414	130.43	7837
1966	55.4	413	134.14	9002
1967	57.7	417	138.37	9145

TABLE A3-19

ASIA MINOR-MIDDLE EAST

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Population (Millions)	Origin Cargo (000 Long Tons)
1950	$2.4	$333	7.21	11
1951	2.7	356	7.58	12
1952	2.8	363	7.71	12
1953	2.8	350	8.00	452
1954	3.0	372	8.06	253
1955	3.2	384	8.33	116
1956	3.4	393	8.65	160
1957	3.5	402	8.71	94
1958	3.7	411	9.00	116
1959	4.0	425	9.41	43
1960	4.1	433	9.47	12
1961	4.4	453	9.71	45
1962	4.8	479	10.02	39
1963	5.2	506	10.28	14
1964	5.6	527	10.63	7
1965	6.1	561	10.87	13
1966	6.2	563	11.01	11
1967	6.5	569	11.42	17

TABLE A3-20

AFRICA

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Population (Millions)	Origin Cargo (000 Long Tons)
1950	24.4	129	189.15	11
1951	25.3	131	193.13	44
1952	26.2	133	196.99	23
1953	27.1	135	200.74	26
1954	28.1	137	205.11	35
1955	29.1	139	209.35	75
1956	30.1	141	213.48	106
1957	31.2	143	218.18	87
1958	32.3	145	222.76	91
1959	33.5	147	227.89	83
1960	34.7	149	232.89	149
1961	36.1	151	239.07	99
1962	37.7	153	246.41	198
1963	39.1	155	252.26	240
1964	41.3	157	263.06	237
1965	43.5	162	268.52	296
1966	45.0	164	274.39	193
1967	46.5	166	280.12	181

TABLE A3-21

WEST COAST USA

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Population (Millions)	Origin Cargo (000 Long Tons)
1950	$ 53.4	$2655	20.11	7759
1951	59.3	2816	21.06	6432
1952	62.0	2852	21.74	5145
1953	65.8	2932	22.44	5154
1954	66.7	2841	23.48	4921
1955	72.3	3004	24.07	6811
1956	75.1	3005	24.99	7432
1957	77.2	2994	25.78	6103
1958	77.9	2910	26.77	5623
1959	83.9	3046	27.54	8031
1960	87.1	3071	28.36	8620
1961	90.0	3078	29.24	6825
1962	97.1	3229	30.07	6912
1963	102.2	3310	30.88	6229
1964	107.8	3442	31.32	7100
1965	115.3	3612	31.92	5669
1966	123.3	3797	32.47	6034
1967	127.1	3847	33.04	4942

TABLE A3-22

WEST COAST CANADA

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Population (Millions)	Origin Cargo (000 Long Tons)
1950	$ 6.8	$1895	3.59	2707
1951	7.2	1966	3.56	2909
1952	7.5	2058	3.64	3645
1953	8.1	2081	3.89	3561
1954	7.5	1961	3.82	4153
1955	8.2	2075	3.95	4089
1956	8.9	2201	4.04	3637
1957	9.3	2154	4.32	3501
1958	9.5	2126	4.47	4577
1959	9.8	2146	4.57	4574
1960	9.6	2151	4.46	4195
1961	10.3	2162	4.76	4135
1962	10.9	2266	4.81	3887
1963	11.5	2341	4.91	4067
1964	12.3	2447	5.03	5123
1965	13.6	2569	5.29	5291
1966	14.4	2660	5.41	5642
1967	14.3	2686	5.32	5059

TABLE A3-23

WEST COAST CENTRAL AMERICA

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Population (Millions)	Origin Cargo (000 Long Tons)
1950	$10.5	$300	35.00	568
1951	11.2	310	36.13	468
1952	11.7	315	37.14	600
1953	11.9	311	38.26	617
1954	12.9	327	39.45	535
1955	13.9	342	40.64	605
1956	14.8	352	42.05	711
1957	15.9	366	43.44	630
1958	16.7	372	44.89	720
1959	17.2	371	46.36	853
1960	18.5	385	48.05	832
1961	19.2	387	49.61	963
1962	20.2	394	51.27	900
1963	21.4	404	52.97	931
1964	23.4	427	54.80	1090
1965	24.7	436	56.65	1713
1966	26.5	451	58.76	1738
1967	28.1	463	60.69	1467

TABLE A3-24

WEST COAST SOUTH AMERICA

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Population (Millions)	Origin Cargo (000 Long Tons)
1950	$ 7.3	$255	28.63	5500
1951	7.6	260	29.23	5856
1952	8.1	270	30.00	5636
1953	8.5	276	30.80	5385
1954	9.0	285	31.58	7264
1955	9.3	285	32.63	6912
1956	9.5	284	33.45	7576
1957	9.9	289	34.26	8913
1958	10.2	288	35.42	10405
1959	10.5	289	36.33	10431
1960	11.2	299	37.46	13123
1961	11.8	306	38.56	12433
1962	12.5	315	39.68	12582
1963	13.0	318	40.88	11879
1964	13.7	325	42.15	11860
1965	14.4	331	43.50	12610
1966	15.1	338	44.67	11401
1967	15.7	341	46.04	10451

TABLE A3-25
OCEANIA

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Pooulation (Millions)	Orgin Cargo (000 Long Tons)
1950	$15.0	$1479	10.14	1328
1951	15.6	1519	10.27	1223
1952	16.0	1525	10.49	1664
1953	15.9	1479	10.75	1700
1954	16.9	1534	11.02	1655
1955	17.9	1590	11.26	1498
1956	18.7	1630	11.47	1651
1957	19.1	1628	11.73	2473
1958	19.5	1630	11.96	1759
1959	20.8	1700	12.24	2065
1960	22.7	1731	13.11	1926
1961	22.8	1781	12.80	1806
1962	23.1	1761	13.12	2066
1963	24.5	1830	13.39	2227
1964	26.0	1919	13.55	2329
1965	27.9	2021	13.81	2501
1966	28.5	2015	14.14	2520
1967	30.0	2094	14.33	2795

TABLE A3-26

JAPAN

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Population (Millions)	Origin Cargo (000 Long Tons)
1950	$ 24.2	$290	83.45	218
1951	26.0	308	84.42	335
1952	28.0	327	85.63	340
1953	30.0	346	86.71	461
1954	31.9	363	87.88	516
1955	34.9	392	89.03	583
1956	37.8	420	90.00	779
1957	42.2	465	90.75	784
1958	43.7	477	91.61	672
1959	48.2	521	92.51	1108
1960	55.6	597	93.13	1217
1961	64.3	683	94.14	1129
1962	69.0	727	94.91	1250
1963	74.3	775	95.87	1750
1964	84.9	877	96.81	2028
1965	88.1	899	98.00	3452
1966	97.5	986	98.88	4876
1967	110.9	1109	100.00	4771

TABLE A3-27

ASIA (LESS JAPAN)

Fiscal Year	GNP (1967 U.S. Billion $)	Per Capita GNP (1967 U.S. Dollars)	Population (Millions)	Origin Cargo (000 Long Tons)
1950	$15.1	$ 96	157.29	1307
1951	15.9	99	160.61	1718
1952	16.6	100	166.00	1449
1953	17.4	102	170.53	1751
1954	18.1	103	175.73	1634
1955	18.9	105	180.00	1671
1956	19.7	107	184.11	2002
1957	20.8	109	190.83	1831
1958	21.5	110	195.45	1453
1959	22.6	112	201.79	1559
1960	23.5	114	206.14	1731
1961	24.5	115	213.04	1912
1962	25.6	117	218.80	2215
1963	27.1	120	225.83	2074
1964	28.4	123	230.89	2114
1965	30.1	127	237.01	2375
1966	32.0	131	244.27	2821
1967	34.7	138	251.45	2712

TABLE A3-28
EAST COAST USA

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	1.78	2655	0.00	0.00
1951	1.76	2816	-1.01	6.06
1952	2.38	2852	35.14	1.28
1953	2.49	2932	4.35	2.81
1954	2.82	2841	13.60	-3.10
1955	2.64	3004	-6.38	5.74
1956	2.82	3005	6.72	.03
1957	3.46	2994	22.55	-.37
1958	2.96	2910	-14.36	-2.81
1959	2.80	3046	-5.34	4.67
1960	3.40	3071	21.19	.82
1961	4.01	3078	18.15	.23
1962	4.12	3229	2.67	4.91
1963	3.35	3310	-18.72	2.51
1964	4.17	3442	24.59	3.99
1965	4.18	3612	.16	4.94
1966	4.34	3797	3.97	5.12
1967	5.00	3847	15.04	1.32

TABLE A3-29

EAST COAST CANADA

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	.96	1895	0.00	0.00
1951	1.18	1966	22.61	3.75
1952	1.29	2058	8.94	4.68
1953	2.33	2081	80.55	1.12
1954	1.77	1961	-24.15	-5.77
1955	1.23	2075	-30.18	5.81
1956	1.36	2201	10.40	6.07
1957	1.77	2154	29.83	-2.14
1958	1.25	2126	-29.52	-1.30
1959	1.01	2146	-18.55	.94
1960	1.71	2151	68.85	.23
1961	2.64	2162	54.16	.51
1962	3.08	2266	16.53	4.81
1963	2.17	2341	-29.45	3.31
1964	2.58	2447	19.06	4.53
1965	2.63	2569	1.88	4.99
1966	1.77	2660	-32.73	3.54
1967	2.57	2686	45.04	.98

TABLE A3-30
EAST COAST CENTRAL AMERICA

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	1.84	300	0.00	0.00
1951	1.42	310	-22.77	3.33
1952	1.81	315	27.64	1.61
1953	1.37	311	-24.41	-1.27
1954	.41	327	-70.01	5.14
1955	.22	342	-45.72	4.59
1956	.41	352	81.78	2.92
1957	.43	366	7.04	3.98
1958	.36	372	-17.21	1.64
1959	.31	371	-12.62	-.27
1960	.74	385	135.88	3.77
1961	.87	387	17.45	.52
1962	1.18	394	36.03	1.81
1963	1.89	404	59.56	2.54
1964	2.41	427	27.45	5.69
1965	2.28	436	-5.26	2.11
1966	3.14	451	37.91	3.44
1967	3.83	463	21.93	2.66

TABLE A3-31

WEST INDIES

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	30.35	230	0.00	0.00
1951	40.03	238	31.87	3.48
1952	62.23	249	55.47	4.62
1953	73.51	259	18.13	4.02
1954	63.98	268	-12.97	3.47
1955	55.94	286	-12.57	6.72
1956	54.96	306	-1.74	6.99
1957	53.68	321	-2.32	4.90
1958	54.43	321	1.39	0.00
1959	53.00	335	-2.63	4.36
1960	48.83	344	-7.87	2.69
1961	79.68	357	63.18	3.78
1962	95.87	353	20.32	-1.12
1963	61.86	350	-35.47	-.85
1964	59.83	364	-3.29	4.00
1965	64.41	376	7.65	3.30
1966	61.49	374	-4.52	-.53
1967	71.64	391	16.51	4.55

TABLE A3-32
EUROPE

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	.62	857	0.00	0.00
1951	.84	902	35.09	5.25
1952	.88	933	5.12	3.44
1953	.76	963	-13.04	3.22
1954	.88	1002	15.80	4.05
1955	.87	1054	-1.80	5.19
1956	.89	1094	2.75	3.80
1957	1.04	1126	16.77	2.93
1958	.84	1140	-19.52	1.24
1959	.76	1181	-9.37	3.60
1960	.82	1246	7.54	5.50
1961	.82	1297	.03	4.09
1962	.80	1338	-2.16	3.16
1963	.71	1383	-11.01	3.36
1964	.68	1450	-4.05	4.84
1965	.67	1495	-2.15	3.10
1966	.69	1533	2.87	2.54
1967	.79	1563	14.29	1.96

TABLE A3-33

EAST COAST SOUTH AMERICA

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	.75	317	0.00	0.00
1951	1.05	323	39.59	1.89
1952	1.56	317	49.43	-1.86
1953	2.71	327	73.53	3.15
1954	2.48	326	-8.62	-.31
1955	3.08	349	24.23	7.06
1956	6.90	349	124.22	0.00
1957	7.27	360	5.29	3.15
1958	8.05	373	10.85	3.61
1959	6.95	375	-13.66	.54
1960	9.84	389	41.55	3.73
1961	11.21	400	13.90	2.83
1962	10.60	401	-5.46	.25
1963	12.88	393	21.54	-2.00
1964	11.98	404	-7.02	2.80
1965	14.51	414	21.16	2.48
1966	16.25	413	11.96	-.24
1967	15.85	417	-2.46	.97

TABLE A3-34
ASIA MINOR, MIDDLE EAST

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	.46	333	0.00	0.00
1951	.44	356	-3.03	6.91
1952	.43	363	-3.57	1.97
1953	16.14	350	3666.67	-3.58
1954	8.43	372	-47.76	6.29
1955	3.63	384	-57.02	3.23
1956	4.71	393	29.82	2.34
1957	2.69	402	-42.93	2.29
1958	3.14	411	16.73	2.24
1959	1.07	425	-65.71	3.41
1960	.29	433	-72.77	1.88
1961	1.02	453	249.43	4.62
1962	.81	479	-20.56	5.74
1963	.27	506	-66.86	5.64
1964	.13	527	-53.57	4.15
1965	.21	561	70.49	6.45
1966	.18	563	-16.75	.36
1967	.26	569	47.41	1.07

TABLE A3-35

AFRICA

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	.05	129	0.00	0.00
1951	.17	131	285.77	1.55
1952	.09	133	-49.52	1.53
1953	.10	135	9.29	1.50
1954	.12	137	29.82	1.48
1955	.26	139	106.92	1.46
1956	.35	141	36.64	1.44
1957	.28	143	-20.82	1.42
1958	.28	145	1.04	1.40
1959	.25	147	-12.06	1.38
1960	.43	149	73.31	1.36
1961	.27	151	-36.13	1.34
1962	.53	153	91.51	1.32
1963	.61	155	16.87	1.31
1964	.57	157	-6.51	1.29
1965	.68	162	18.58	3.18
1966	.43	164	-36.97	1.23
1967	.39	166	-9.24	1.22

TABLE A3-36
WEST COAST USA

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	14.53	2655	0.00	0.00
1951	10.85	2816	-25.35	6.06
1952	8.30	2852	-23.49	1.28
1953	7.83	2932	-5.61	2.81
1954	7.38	2841	-5.81	-3.10
1955	9.42	3004	27.69	5.74
1956	9.90	3005	5.05	.03
1957	7.91	2994	-20.12	-.37
1958	7.22	2910	-8.69	-2.81
1959	9.57	3046	32.61	4.67
1960	9.90	3071	3.39	.82
1961	7.58	3078	-23.37	.23
1962	7.12	3229	-6.13	4.91
1963	6.09	3310	-14.38	2.51
1964	6.59	3442	9.06	3.99
1965	4.92	3612	-25.35	4.94
1966	4.89	3797	-.47	5.12
1967	3.89	3847	-20.55	1.32

TABLE A3-37
WEST COAST CANADA

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	39.81	1895	0.00	0.00
1951	40.40	1966	1.49	3.75
1952	48.60	2058	20.29	4.68
1953	43.96	2081	-9.54	1.12
1954	55.37	1961	25.95	-5.77
1955	49.87	2075	-9.95	5.81
1956	40.87	2201	-18.05	6.07
1957	37.65	2154	-7.88	-2.14
1958	48.18	2126	27.98	-1.30
1959	46.67	2146	-3.12	.94
1960	43.70	2151	-6.38	.23
1961	40.15	2162	-8.13	.51
1962	35.66	2266	-11.17	4.81
1963	35.37	2341	-.83	3.31
1964	41.65	2447	17.77	4.53
1965	38.90	2569	-6.59	4.99
1966	39.18	2660	.71	3.54
1967	35.38	2686	-9.71	.98

TABLE A3-38
WEST COAST CENTRAL AMERICA

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	5.41	300	0.00	0.00
1951	4.18	310	-22.76	3.33
1952	5.13	315	22.73	1.61
1953	5.18	311	1.11	-1.27
1954	4.15	327	-20.01	5.14
1955	4.35	342	4.95	4.59
1956	4.80	352	10.37	2.92
1957	3.96	366	-17.52	3.98
1958	4.31	372	8.81	1.64
1959	4.96	371	15.03	-.27
1960	4.50	385	-9.32	3.77
1961	5.02	387	11.53	.52
1962	4.46	394	-11.17	1.81
1963	4.35	404	2.36	2.54
1964	4.66	427	7.07	5.69
1965	6.94	436	48.38	2.11
1966	6.56	451	-5.43	3.44
1967	5.22	463	-20.40	2.66

TABLE A3-39

WEST COAST SOUTH AMERICA

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	75.34	255	0.00	0.00
1951	77.05	260	2.27	1.96
1952	69.58	270	-9.70	3.85
1953	63.35	276	-8.95	2.22
1954	80.71	285	27.40	3.26
1955	74.32	285	-7.92	0.00
1956	79.75	284	7.30	-.35
1957	90.03	289	12.89	1.76
1958	102.01	288	13.31	-.35
1959	99.34	289	-2.61	.35
1960	117.17	299	17.94	3.46
1961	105.36	306	-10.08	2.34
1962	100.66	315	-4.47	2.94
1963	91.38	318	-9.22	.95
1964	86.57	325	-5.26	2.20
1965	87.57	331	1.16	1.85
1966	75.50	338	-13.78	2.11
1967	66.57	341	-11.84	.89

TABLE A3-40
OCEANIA

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	8.85	1479	0.00	0.00
1951	7.84	1519	-11.45	2.70
1952	10.40	1525	32.66	.39
1953	10.69	1479	2.81	-3.02
1954	9.79	1534	-8.41	3.72
1955	8.37	1590	-14.54	3.65
1956	8.83	1630	5.50	2.52
1957	12.95	1628	46.65	-.12
1958	9.02	1630	-30.33	.12
1959	9.93	1700	10.06	4.29
1960	8.48	1731	-14.54	1.82
1961	7.92	1781	-6.64	2.89
1962	8.94	1761	12.91	-1.12
1963	9.09	1830	1.63	3.92
1964	8.96	1919	-1.45	4.86
1965	8.96	2021	.07	5.32
1966	8.84	2015	-1.36	-.30
1967	9.32	2094	5.37	3.92

TABLE A3-41

JAPAN

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	.90	290	0.00	0.00
1951	1.29	308	43.03	6.21
1952	1.21	327	-5.76	6.17
1953	1.54	346	26.55	5.81
1954	1.62	363	5.26	4.91
1955	1.67	392	3.27	7.99
1956	2.06	420	23.37	7.14
1957	1.86	465	-9.85	10.71
1958	1.54	477	-17.23	2.58
1959	2.30	521	49.49	9.22
1960	2.19	597	-4.78	14.59
1961	1.76	683	-19.78	14.41
1962	1.81	727	3.18	6.44
1963	2.36	775	30.01	6.60
1964	2.39	877	1.42	13.16
1965	3.92	899	64.03	2.15
1966	5.00	986	27.63	9.68
1967	4.30	1109	-13.98	12.47

TABLE A3-42
ASIA (LESS JAPAN)

Fiscal Year	Ratio Cargo Tonnage/GNP	Per Capita GNP	Percent Change Ton/GNP	Percent Change Per Capita GNP
1950	8.66	96	0.00	0.00
1951	10.81	99	24.83	3.13
1952	8.73	100	-19.21	1.01
1953	10.06	102	15.29	2.00
1954	9.03	103	-10.29	.98
1955	8.84	105	-2.06	1.94
1956	10.16	107	14.94	1.90
1957	8.80	109	-13.38	1.87
1958	6.76	110	-23.23	.92
1959	6.90	112	2.07	1.82
1960	7.37	114	6.78	1.79
1961	7.80	115	5.95	.88
1962	8.65	117	10.87	1.74
1963	7.65	120	-11.55	2.56
1964	7.44	123	-2.74	2.50
1965	7.89	127	6.00	3.25
1966	8.82	131	11.73	3.15
1967	7.82	138	-11.34	5.34

CURVE ANALYSIS
15 REGIONS – 3 CURVE TYPES
TABLES 43 THROUGH 65

Note: Associated with each curve analysis is an index figure and a correlation coefficient. Once a historical relationship has been established between the region's product and cargo tonnage, the index, which reflects a correlation between the region's product and time, is used to determine a forecast of product. The correlation coefficient is used to determine a forecast of cargo tonnage.

TABLE A3-43

EAST COAST USA				EAST COAST USA			
Curve: 1 Index: .931883 Corrl: .976				Curve: 2 Index: .79589 Corrl: .976			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$ 617.0		28031.0	1968	$555.2		22912.3
1969	632.3	2.5	29301.4	1969	560.7	1.0	23371.0
1970	647.7	2.4	30571.9	1970	566.0	.9	23811.6
1971	663.0	2.4	31842.3	1971	571.1	.9	24235.6
1972	678.4	2.3	33112.8	1972	576.1	.9	24644.4
1973	693.7	2.3	34383.2	1973	580.8	.8	25039.0
1974	709.0	2.2	35653.7	1974	585.5	.8	25420.6
1975	724.4	2.2	36924.1	1975	589.9	.8	25790.0
1976	739.7	2.1	38194.5	1976	594.2	.7	26148.2
1977	755.1	2.1	39465.0	1977	598.4	.7	26495.9
1978	770.4	2.0	40735.4	1978	602.5	.7	26833.6
1979	785.8	2.0	42005.9	1979	606.5	.7	27162.2
1980	801.1	2.0	43276.3	1980	610.3	.6	27481.9
1981	816.4	1.9	44546.8	1981	614.1	.6	27793.5
1982	831.8	1.9	45817.2	1982	617.8	.6	28097.3
1983	847.1	1.8	47087.7	1983	621.4	.6	28393.8
1984	862.5	1.8	48358.1	1984	624.9	.6	28683.4
1985	877.8	1.8	49628.6	1985	628.3	.5	28966.3

TABLE A3-43 (Cont'd.)

	EAST COAST USA				EAST COAST USA		
	Curve: 1 Index: .931883 Corrl: .976				Curve: 2 Index: .79[illegible]589 Corrl: .976		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$893.2	1.7	50899.0	1986	$631.6	.5	29243.0
1987	908.5	1.7	52169.4	1987	634.9	.5	29513.7
1988	923.9	1.7	53439.9	1988	638.1	.5	29778.7
1989	939.2	1.7	54710.3	1989	641.2	.5	30038.3
1990	954.5	1.6	55980.8	1990	644.3	.5	30292.7
1991	969.9	1.6	57251.2	1991	647.3	.5	30542.2
1992	985.2	1.6	58521.7	1992	650.3	.5	30786.9
1993	1000.6	1.6	59792.1	1993	653.2	.4	31027.0
1994	1015.9	1.5	61062.6	1994	656.0	.4	31262.8
1995	1031.3	1.5	62333.0	1995	658.8	.4	31494.5
1996	1046.6	1.5	63603.5	1996	661.6	.4	31722.0
1997	1061.9	1.5	64873.9	1997	664.3	.4	31945.8
1998	1077.3	1.4	66144.4	1998	666.9	.4	32165.7
1999	1092.6	1.4	67414.8	1999	669.5	.4	32382.1
2000	1108.0	1.4	68685.2	2000	672.1	.4	32595.1

TABLE A3-44

	EAST COAST USA				EAST COAST CANADA		
	Curve: 3 Index: .960518 Corrl: .976				Curve: 1 Index: .962808 Corrl: .849		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$ 629.4		29059.2	1968	$39.5		969.0
1969	649.9	3.3	30754.4	1969	40.7	2.9	1012.9
1970	671.0	3.3	32504.7	1970	41.8	2.8	1056.9
1971	692.8	3.3	34311.9	1971	43.0	2.8	1100.9
1972	715.4	3.3	36177.9	1972	44.1	2.7	1144.8
1973	738.6	3.3	38104.6	1973	45.3	2.6	1188.8
1974	762.7	3.3	40094.0	1974	46.4	2.6	1232.8
1975	787.5	3.3	42148.1	1975	47.6	2.5	1276.8
1976	813.1	3.3	44269.0	1976	48.8	2.4	1320.7
1977	839.5	3.3	46458.9	1977	49.9	2.4	1364.7
1978	866.8	3.3	48720.1	1978	51.1	2.3	1408.7
1979	895.0	3.3	51054.8	1979	52.2	2.3	1452.6
1980	924.2	3.3	53465.4	1980	53.4	2.2	1496.6
1981	954.2	3.3	55954.4	1981	54.5	2.2	1540.6
1982	985.3	3.3	58524.5	1982	55.7	2.1	1584.6
1983	1017.3	3.3	61178.1	1983	56.9	2.1	1628.5
1984	1050.4	3.3	63918.0	1984	58.0	2.0	1672.5
1985	1084.6	3.3	66747.0	1985	59.2	2.0	1716.5

TABLE A3-44 (Cont'd)

	EAST COAST USA				EAST COAST CANADA		
	Curve: 3 Index: .960518 Corrl: .976				Curve: 1 Index: .962808 Corrl: .849		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$1119.8	3.3	69688.1	1986	$60.3	2.0	1760.5
1987	1156.3	3.3	72684.2	1987	61.5	1.9	1804.4
1988	1193.9	3.3	75798.3	1988	62.6	1.9	1848.4
1989	1232.7	3.3	79013.8	1989	63.8	1.8	1892.4
1990	1272.8	3.3	82333.9	1990	65.0	1.8	1936.3
1991	1314.2	3.3	85762.0	1991	66.1	1.8	1980.3
1992	1357.0	3.3	89301.6	1992	67.3	1.8	2024.3
1993	1401.1	3.3	92956.3	1993	68.4	1.7	2068.3
1994	1446.7	3.3	96729.9	1994	69.6	1.7	2112.2
1995	1493.7	3.3	100626.2	1995	70.7	1.7	2156.2
1996	1542.3	3.3	104649.3	1996	71.9	1.6	2200.2
1997	1592.5	3.3	108803.2	1997	73.1	1.6	2244.2
1998	1644.3	3.3	113092.3	1998	74.2	1.6	2288.1
1999	1697.8	3.3	117520.9	1999	75.4	1.6	2332.1
2000	1753.0	3.3	122093.5	2000	76.5	1.5	2376.1

TABLE A3-45

EAST COAST CANADA Curve: 2 Index: .859973 Corrl: .849				EAST COAST CANADA Curve: 3 Index: .981640 Corrl: .849			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$35.2		805.3	1968	$41.0		1025.4
1969	35.7	1.3	822.8	1969	42.7	4.1	1090.0
1970	36.1	1.2	839.7	1970	44.5	4.1	1157.2
1971	36.5	1.2	855.9	1971	46.3	4.1	1227.2
1972	36.9	1.1	871.6	1972	48.2	4.1	1300.2
1973	37.3	1.1	886.8	1973	50.2	4.1	1376.1
1974	37.7	1.0	901.5	1974	52.3	4.1	1455.2
1975	38.1	1.0	915.8	1975	54.5	4.1	1537.5
1976	38.5	1.0	929.7	1976	56.7	4.1	1623.3
1977	38.8	.9	943.2	1977	59.1	4.1	1712.6
1978	39.2	.9	956.4	1978	61.5	4.1	1805.7
1979	39.5	.9	969.2	1979	64.1	4.1	1902.6
1980	39.8	.8	981.7	1980	66.7	4.1	2003.5
1981	40.2	.8	993.9	1981	69.5	4.1	2108.6
1982	40.5	.8	1005.9	1982	72.4	4.1	2218.0
1983	40.8	.8	1017.5	1983	75.4	4.1	2332.0
1984	41.1	.7	1028.9	1984	78.5	4.1	2450.7
1985	41.4	.7	1040.1	1985	81.7	4.1	2574.3

TABLE A3-45 (Cont'd)

	EAST COAST CANADA				EAST COAST CANADA		
	Curve: 2 Index: .859973 Corrl: .849				Curve: 3 Index: .981640 Corrl: .849		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$41.7	.7	1051.1	1986	$ 85.1	4.1	2703.1
1987	41.9	.7	1061.8	1987	88.7	4.1	2837.1
1988	42.2	.7	1072.3	1988	92.3	4.1	2976.8
1989	42.5	.6	1082.6	1989	96.2	4.1	3122.2
1990	42.8	.6	1092.7	1990	100.1	4.1	3272.7
1991	43.0	.6	1102.7	1991	104.3	4.1	3431.4
1992	43.3	.6	1112.4	1992	108.6	4.1	3595.7
1993	43.5	.6	1122.0	1993	113.1	4.1	3766.7
1994	43.8	.6	1131.4	1994	117.8	4.1	3944.9
1995	44.0	.6	1140.7	1995	122.7	4.1	4130.5
1996	44.3	.5	1149.9	1996	127.8	4.1	4323.7
1997	44.5	.5	1158.8	1997	133.1	4.1	4525.0
1998	44.7	.5	1167.7	1998	138.6	4.1	4734.6
1999	45.0	.5	1176.4	1999	144.3	4.1	4952.9
2000	45.2	.5	1185.0	2000	150.3	4.1	5180.2

TABLE A3-46

EAST COAST CENTRAL AMERICA

Curve: 1 Index: .973394 Corrl: .826

Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$27.3		709.9
1969	28.3	3.7	755.2
1970	29.3	3.6	800.5
1971	30.3	3.4	845.8
1972	31.3	3.3	891.1
1973	32.3	3.2	936.4
1974	33.3	3.1	981.6
1975	34.3	3.0	1026.9
1976	35.3	2.9	1072.2
1977	36.3	2.8	1117.2
1978	37.3	2.8	1162.8
1979	38.3	2.7	1208.1
1980	39.9	2.6	1253.3
1981	40.3	2.6	1298.6
1982	41.4	2.5	1343.9
1983	42.4	2.4	1389.2
1984	43.4	2.4	1434.5
1985	44.4	2.3	1479.8

EAST COAST CENTRAL AMERICA

Curve: 2 Index: .858997 Corrl: .826

Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$23.5		541.0
1969	23.9	1.8	560.4
1970	24.4	1.8	579.3
1971	24.8	1.7	597.6
1972	25.2	1.6	615.3
1973	25.5	1.5	632.6
1974	25.9	1.5	649.4
1975	26.3	1.4	665.8
1976	26.6	1.4	681.8
1977	27.0	1.3	697.4
1978	27.3	1.3	712.7
1979	27.7	1.2	727.6
1980	28.0	1.2	742.2
1981	28.3	1.1	756.5
1982	28.6	1.1	770.5
1983	28.9	1.1	784.2
1984	29.2	1.0	797.7
1985	29.5	1.0	811.0

TABLE A3-46 (Cont'd.)

EAST COAST CENTRAL AMERICA Curve: 1 Index: .973394 Corrl: .826				EAST COAST CENTRAL AMERICA Curve: 2 Index: .858997 Corrl: .826			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$45.4	2.3	1525.0	1986	$29.8	1.0	824.0
1987	46.4	2.2	1570.3	1987	30.1	1.0	836.7
1988	47.4	2.2	1615.6	1988	30.4	.9	849.3
1989	48.4	2.1	1660.9	1989	30.6	.9	861.7
1990	49.4	2.1	1706.2	1990	30.9	.9	873.8
1991	50.4	2.0	1751.5	1991	31.2	.9	885.8
1992	51.4	2.0	1796.7	1992	31.4	.8	897.6
1993	52.4	2.0	1842.0	1993	31.7	.8	909.2
1994	53.4	1.9	1887.3	1994	31.9	.8	920.6
1995	54.4	1.9	1932.6	1995	32.2	.8	931.9
1996	55.4	1.8	1977.9	1996	32.4	.8	943.1
1997	56.4	1.8	2023.2	1997	32.7	.8	954.0
1998	57.5	1.8	2068.4	1998	32.9	.7	964.9
1999	58.5	1.8	2113.7	1999	33.2	.7	975.5
2000	59.5	1.7	2159.0	2000	33.4	.7	986.1

TABLE A3-47

EAST COAST CENTRAL AMERICA				WEST INDIES			
Curve: 3 Index: .996763 Corrl: .826				Curve: 1 Index: .995561 Corrl: .878			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$29.3		799.4	1968	$ 9.0		6166.8
1969	31.0	5.9	877.4	1969	9.3	3.5	6425.5
1970	32.8	5.9	960.0	1970	9.6	3.4	6684.2
1971	34.8	5.9	1047.5	1971	9.9	3.3	6942.9
1972	36.8	5.9	1140.2	1972	10.2	3.2	7201.6
1973	39.0	5.9	1238.3	1973	10.5	3.1	7460.3
1974	41.3	5.9	1342.3	1974	10.9	3.0	7719.0
1975	43.8	5.9	1452.4	1975	11.2	2.9	7977.7
1976	46.4	5.9	1569.1	1976	11.5	2.8	8236.4
1977	49.1	5.9	1692.7	1977	11.8	2.7	8495.1
1978	52.0	5.9	1823.5	1978	12.1	2.7	8753.7
1979	55.1	5.9	1962.2	1979	12.4	2.6	9012.4
1980	58.4	5.9	2109.0	1980	12.8	2.5	9271.1
1981	61.8	5.9	2264.6	1981	13.1	2.5	9529.8
1982	65.5	5.9	2429.4	1982	13.4	2.4	9788.5
1983	69.4	5.9	2603.9	1983	13.7	2.4	10047.2
1984	73.5	5.9	2788.7	1984	14.0	2.3	10305.9
1985	77.8	5.9	2984.6	1985	14.3	2.3	10564.6

TABLE A3-47 (Cont'd)

	EAST COAST CENTRAL AMERICA Curve: 3 Index: .996763 Corrl: .826				WEST INDIES Curve: 1 Index: .995561 Corrl: .878		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	82.4	5.9	3192.0	1906	14.6	2.2	10823.2
1987	87.3	5.9	3411.7	1987	15.0	2.2	11082.0
1988	92.5	5.9	3644.4	1988	15.3	2.1	11340.7
1989	98.0	5.9	3890.9	1989	15.6	2.1	11599.4
1990	103.8	5.9	4152.0	1990	15.9	2.0	11858.1
1991	109.9	5.9	4428.5	1991	16.2	2.0	12116.8
1992	116.4	5.9	4721.5	1992	16.5	1.9	12375.5
1993	123.3	5.9	5031.8	1993	16.9	1.9	12634.2
1994	130.6	5.9	5360.4	1994	17.2	1.9	12892.8
1995	138.3	5.9	5708.6	1995	17.5	1.8	13151.5
1996	146.5	5.9	6077.3	1996	17.8	1.8	13410.2
1997	155.2	5.9	6468.0	1997	18.1	1.8	13668.9
1998	164.4	5.9	6881.7	1998	18.4	1.7	13927.6
1999	174.2	5.9	7320.0	1999	18.7	1.7	14186.3
2000	184.5	5.9	7784.2	2000	19.1	1.7	14445.0

TABLE A3-48

	WEST INDIES Curve: 2 Index: .926643 Corrl: .878				WEST INDIES Curve: 3 Index: .979622 Corrl: .878		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$8.0		5361.9	1968	$ 9.7		6777.4
1969	8.1	1.9	5483.7	1969	10.3	5.7	7231.7
1970	8.3	1.8	5601.6	1970	10.9	5.7	7712.1
1971	8.4	1.7	5716.1	1971	11.5	5.7	8219.8
1972	8.6	1.6	5827.2	1972	12.1	5.7	8756.4
1973	8.7	1.5	5935.3	1973	12.8	5.7	9323.7
1974	8.8	1.5	6040.5	1974	13.6	5.7	9923.2
1975	8.9	1.4	6143.1	1975	14.3	5.7	10557.2
1976	9.1	1.4	6243.1	1976	15.1	5.7	11227.2
1977	9.2	1.3	6340.8	1977	16.0	5.7	11935.4
1978	9.3	1.3	6436.3	1978	16.9	5.7	12684.0
1979	9.4	1.2	6529.8	1979	17.9	5.7	13475.3
1980	9.5	1.2	6621.2	1980	18.9	5.7	14311.8
1981	9.6	1.1	6710.8	1981	20.0	5.7	15196.0
1982	9.7	1.1	6798.6	1982	21.1	5.7	16130.6
1983	9.8	1.1	6884.7	1983	22.3	5.7	17118.5
1984	9.9	1.0	6969.2	1984	23.6	5.7	18162.8
1985	10.0	1.0	7052.2	1985	24.9	5.7	19266.7

TABLE A3-48 (Cont'd.)

WEST INDIES Curve: 2 Index: .926643 Corrl: .878				WEST INDIES Curve: 3 Index: .979622 Corrl: .878			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	10.1	1.0	7133.7	1986	26.4	5.7	20433.5
1987	10.2	1.0	7213.8	1987	27.9	5.7	21666.9
1988	10.3	.9	7292.5	1988	29.5	5.7	22970.7
1989	10.4	.9	7370.0	1989	31.1	5.7	24348.8
1990	10.5	.9	7446.3	1990	32.9	5.7	25805.5
1991	10.6	.9	7521.3	1991	34.8	5.7	27345.4
1992	10.7	.8	7595.3	1992	36.8	5.7	28973.0
1993	10.8	.8	7668.1	1993	36.9	5.7	30693.6
1994	10.9	.8	7739.9	1994	41.1	5.7	32512.2
1995	11.0	.8	7810.6	1995	43.4	5.7	34434.7
1996	11.1	.8	7880.4	1996	45.9	5.7	36466.7
1997	11.1	.8	7949.3	1997	48.5	5.7	38614.8
1998	11.2	.7	8017.2	1998	51.3	5.7	40885.3
1999	11.3	.7	8084.3	1999	54.2	5.7	43285.3
2000	11.4	.7	8150.5	2000	57.3	5.7	45822.3

TABLE A3-49

EUROPE Curve: 1 Index: .989162 Corrl: .856				EUROPE Curve: 2 Index: .875949 Corrl: .856			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$564.4		4108.8	1968	$499.6		3726.8
1969	582.2	3.2	4214.1	1969	507.0	1.5	3770.4
1970	600.1	3.1	4319.5	1970	514.1	1.4	3812.4
1971	617.9	3.0	4424.8	1971	521.0	1.3	3853.0
1972	635.8	2.9	4530.2	1972	527.7	1.3	3892.3
1973	653.2	2.8	4635.5	1973	534.1	1.2	3930.4
1974	671.5	2.7	4740.9	1974	540.4	1.2	3967.4
1975	689.4	2.7	4846.2	1975	546.5	1.1	4003.4
1976	707.2	2.6	4951.6	1976	552.4	1.1	4038.4
1977	725.1	2.5	5056.9	1977	558.2	1.0	4072.5
1978	742.9	2.5	5162.3	1978	563.8	1.0	4105.7
1979	760.8	2.4	5267.6	1979	569.3	1.0	4138.1
1980	778.6	2.3	5373.0	1980	574.7	.9	4169.7
1981	796.5	2.3	5478.3	1981	579.9	.9	4200.6
1982	814.3	2.2	5583.7	1982	585.1	.9	4230.9
1983	832.2	2.2	5689.0	1983	590.1	.9	4260.5
1984	850.1	2.1	5794.4	1984	595.0	.8	4289.4
1985	867.9	2.1	5899.7	1985	599.8	.8	4317.8

TABLE A3-49 (Cont'd)

EUROPE				EUROPE			
Curve: 1 Index: .989162 Corrl: .856				Curve: 2 Index: .875949 Corrl: .856			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	885.8	2.1	6005.1	1986	604.5	.8	4345.7
1987	903.6	2.0	6110.4	1987	609.1	.8	4373.0
1988	921.5	2.0	6215.7	1988	613.7	.7	4399.7
1989	939.3	1.9	6321.1	1989	618.1	.7	4426.0
1990	957.2	1.9	6426.4	1990	622.5	.7	4451.9
1991	975.0	1.9	6531.8	1991	626.8	.7	4477.3
1992	992.9	1.8	6637.1	1992	631.1	.7	4502.2
1993	1010.8	1.8	6742.5	1993	635.2	.7	4526.8
1994	1028.6	1.8	6847.8	1994	639.3	.6	4551.0
1995	1046.5	1.7	6953.2	1995	643.3	.6	4574.7
1996	1064.3	1.7	7058.5	1996	647.3	.6	4598.2
1997	1082.2	1.7	7163.9	1997	651.2	.6	4621.2
1998	1100.0	1.6	7269.2	1998	655.1	.6	4643.9
1999	1117.9	1.6	7374.6	1999	658.9	.6	4666.3
2000	1135.7	1.6	7479.9	2000	662.6	.6	4688.4

TABLE A3-50

	EUROPE				EAST COAST SOUTH AMERICA		
	Curve: 3 Index: .997958 Corrl: .856				Curve: 1 Index: .993088 Corrl: .984		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast Percent Change	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$ 593.2		4279.0	1968	$58.9		8996.0
1969	621.1	4.7	4443.2	1969	60.8	3.2	9547.0
1970	650.2	4.7	4615.1	1970	62.6	3.1	10098.1
1971	680.7	4.7	4795.0	1971	64.5	3.0	10649.1
1972	712.6	4.7	4983.4	1972	66.3	2.9	11200.1
1973	746.0	4.7	5180.6	1973	68.2	2.8	11751.2
1974	781.0	4.7	5387.0	1974	70.1	2.7	12302.2
1975	817.7	4.7	5603.2	1975	71.9	2.7	12853.2
1976	856.0	4.7	5829.4	1976	73.8	2.6	13404.3
1977	896.2	4.7	6066.3	1977	75.7	2.5	13955.3
1978	938.2	4.7	6314.3	1978	77.5	2.5	14506.3
1979	982.2	4.7	6574.0	1979	79.4	2.4	15057.4
1980	1028.3	4.7	6845.8	1980	81.2	2.3	15608.4
1981	1076.5	4.7	7130.3	1981	83.1	2.3	16159.5
1982	1127.0	4.7	7428.2	1982	85.0	2.2	16710.5
1983	1179.9	4.7	7740.1	1983	86.8	2.2	17261.5
1984	1235.2	4.7	8066.6	1984	88.7	2.1	17812.6
1985	1293.1	4.7	8408.5	1985	90.5	2.1	18363.6

TABLE A3-50 (Cont'd.)

EUROPE				EAST COAST SOUTH AMERICA			
Curve: 3 Index: .997958 Corrl: .856				Curve: 1 Index: .993088 Corrl: .984			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	1353.8	4.7	8766.3	1986	92.4	2.1	18914.6
1987	1417.3	4.7	9141.0	1987	94.3	2.0	19465.7
1988	1483.8	4.7	9533.2	1988	96.1	2.0	20016.7
1989	1553.4	4.7	9943.8	1989	98.0	1.9	20567.7
1990	1626.2	4.7	10373.7	1990	99.9	1.9	21118.8
1991	1702.5	4.7	10823.7	1991	101.7	1.9	21669.8
1992	1782.3	4.7	11294.8	1992	103.6	1.8	22220.9
1993	1865.9	4.7	11768.1	1993	105.4	1.8	22771.9
1994	1953.5	4.7	12304.5	1994	107.3	1.8	23322.9
1995	2045.1	4.7	12845.1	1995	109.2	1.7	23847.0
1996	2141.0	4.7	13411.0	1996	111.0	1.7	24425.0
1997	2241.4	4.7	14002.5	1997	112.9	1.7	24976.0
1998	2346.6	4.7	14623.8	1998	114.8	1.6	25527.1
1999	2456.6	4.7	15273.2	1999	116.6	1.6	26078.1
2000	2571.9	4.7	15953.1	2000	118.5	1.6	26629.2

TABLE A3-51

EAST COAST SOUTH AMERICA Curve: 2 Index: .881609 Corrl: .984				EAST COAST SOUTH AMERICA Curve: 3 Index: .992185 Corrl: .984			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$52.3		7055.2	1968	$ 62.1		9953.2
1969	53.1	1.5	7287.4	1969	65.1	4.7	10822.9
1970	53.9	1.4	7511.5	1970	68.2	4.7	11733.8
1971	54.6	1.4	7728.1	1971	71.4	4.7	12687.8
1972	55.3	1.3	7937.9	1972	74.7	4.7	13686.9
1973	56.0	1.2	8141.2	1973	78.3	4.7	14733.2
1974	56.7	1.2	8338.7	1974	82.0	4.7	15829.1
1975	57.3	1.1	8530.6	1975	85.9	4.7	16976.7
1976	58.0	1.1	8717.3	1976	89.9	4.7	18178.6
1977	58.6	1.1	8899.2	1977	94.2	4.7	19437.4
1978	59.2	1.0	9076.5	1978	98.6	4.7	20755.6
1979	59.8	1.0	9249.6	1979	103.3	4.7	22136.3
1980	60.3	1.0	9418.6	1980	108.2	4.7	23582.2
1981	60.9	.9	9583.8	1981	113.3	4.7	25096.4
1982	61.4	.9	9745.3	1982	118.7	4.7	26682.3
1983	62.0	.9	9903.4	1983	124.3	4.7	28343.2
1984	62.5	.8	10058.2	1984	130.1	4.7	30082.7
1985	63.0	.8	10210.0	1985	136.3	4.7	31904.4

TABLE A3-51 (Cont'd)

	EAST COAST SOUTH AMERICA				EAST COAST SOUTH AMERICA		
	Curve: 2 Index: .881609 Corrl: .984				Curve: 3 Index: .992185 Corrl: .984		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	63.5	.8	10358.7	1986	142.7	4.7	33812.2
1987	64.0	.8	10504.6	1987	149.5	4.7	35810.3
1988	64.5	.8	10647.9	1988	156.6	4.7	37902.8
1989	65.0	.7	10788.5	1989	164.0	4.7	40094.3
1990	65.4	.7	10926.7	1990	171.7	4.7	42389.5
1991	65.9	.7	11062.5	1991	179.8	4.7	44793.2
1992	66.3	.7	11196.0	1992	188.3	4.7	47310.5
1993	66.8	.7	11327.4	1993	197.2	4.7	49946.9
1994	67.2	.7	11456.6	1994	206.6	4.7	52708.0
1995	67.6	.6	11583.8	1995	216.3	4.7	55599.7
1996	68.1	.6	11709.1	1996	226.6	4.7	58628.1
1997	68.5	.6	11832.4	1997	237.3	4.7	61799.7
1998	63.9	.6	11954.0	1998	248.5	4.7	65121.3
1999	69.3	.6	12073.8	1999	260.3	4.7	68599.9
2000	69.7	.6	12192.0	2000	272.6	4.7	72243.1

TABLE A3-52

ASIA, MIDDLE EAST				ASIA, MIDDLE EAST			
Curve: 1 Index: .959059 Corrl: .995 (Adjusted)				Curve: 2 Index: .833157 Corrl: .995 (Adjusted)			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$6.4		13.2	1968	$5.5		7.0
1969	6.7	3.8	14.9	1969	5.6	1.9	7.6
1970	6.9	3.6	16.5	1970	5.7	1.8	8.3
1971	7.2	3.5	18.1	1971	5.8	1.7	8.9
1972	7.4	3.4	19.7	1972	5.9	1.6	9.6
1973	7.6	3.3	21.3	1973	6.0	1.5	10.2
1974	7.9	3.2	22.9	1974	6.1	1.5	10.7
1975	8.1	3.1	24.5	1975	6.1	1.4	11.3
1976	8.4	3.0	26.1	1976	6.2	1.4	11.9
1977	8.6	2.9	27.7	1977	6.3	1.3	12.4
1978	8.8	2.8	29.3	1978	6.4	1.3	12.9
1979	9.1	2.7	31.0	1979	6.5	1.2	13.5
1980	9.3	2.7	32.6	1980	6.5	1.2	14.4
1981	9.6	2.6	34.2	1981	6.6	1.1	14.5
1982	9.8	2.5	35.8	1982	6.7	1.1	15.0
1983	10.0	2.5	37.4	1983	6.8	1.1	15.4
1984	10.3	2.4	39.0	1984	6.8	1.0	15.9
1985	10.5	2.3	40.6	1985	6.9	1.0	16.4

TABLE A3-52 (Cont'd.)

ASIA, MIDDLE EAST Curve: 1 Index: .959059 Corrl: .995 (Adjusted)				ASIA, MIDDLE EAST Curve: 2 Index: .833157 Corrl: .995 (Adjusted)			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$10.8	2.3	42.2	1986	$7.0	1.0	16.8
1987	11.0	2.2	43.8	1987	7.0	1.0	17.3
1988	11.3	2.2	45.4	1988	7.1	.9	17.7
1989	11.5	2.1	47.1	1989	7.2	.9	18.1
1990	11.7	2.1	48.7	1990	7.2	.9	18.6
1991	12.0	2.1	50.3	1991	7.3	.9	19.0
1992	12.2	2.0	51.9	1992	7.3	.8	19.4
1993	12.5	2.0	53.5	1993	7.4	.8	19.8
1994	12.7	1.9	55.1	1994	7.5	.8	20.2
1995	12.9	1.9	56.7	1995	7.5	.8	20.6
1996	13.2	1.9	58.3	1996	7.6	.8	21.0
1997	13.4	1.8	59.9	1997	7.6	.8	21.4
1998	13.7	1.8	61.5	1998	7.7	.7	21.7
1999	13.9	1.8	63.1	1999	7.8	.7	22.1
2000	14.2	1.7	64.8	2000	7.8	.7	22.5

TABLE A3-53

ASIA, MIDDLE EAST				AFRICA			
Curve: 3 Index: .990402 Corrl: .995 (Adjusted)				Curve: 1 Index: .980297 Corrl: .890			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$ 6.9		16.3	1968	$46.2		254.0
1969	7.3	6.0	19.0	1969	47.5	2.8	268.1
1970	7.7	6.0	22.0	1970	48.8	2.7	282.2
1971	8.2	6.0	25.1	1971	50.1	2.6	296.3
1972	8.7	6.0	28.4	1972	51.4	2.6	310.4
1973	9.2	6.0	31.9	1973	52.7	2.5	324.5
1974	9.8	6.0	35.6	1974	54.0	2.5	338.6
1975	10.4	6.0	39.5	1975	55.3	2.4	352.7
1976	11.0	6.0	43.7	1976	56.6	2.3	366.8
1977	11.7	6.0	48.1	1977	57.9	2.3	380.9
1978	12.4	6.0	52.8	1978	59.2	2.2	395.0
1979	13.1	6.0	57.8	1979	60.5	2.2	409.1
1980	13.9	6.0	63.1	1980	61.8	2.1	423.2
1981	14.7	6.0	68.7	1981	63.1	2.1	437.3
1982	15.6	6.0	74.6	1982	64.3	2.1	451.4
1983	16.6	6.0	80.9	1983	65.6	2.0	465.5
1984	17.6	6.0	87.6	1984	66.9	2.0	479.6
1985	18.6	6.0	94.6	1985	68.2	1.9	493.7

TABLE A3-53 (Cont'd.)

ASIA, MIDDLE EAST				AFRICA			
Curve: 3 Index: .990402 Corrl: .995 (Adjusted)				Curve: 1 Index: .980297 Corrl: .890			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$19.8	6.0	102.1	1986	$69.5	1.9	507.8
1987	21.0	6.0	110.1	1987	70.8	1.9	521.9
1988	22.2	6.0	118.5	1988	72.1	1.8	536.0
1989	23.6	6.0	127.4	1989	73.4	1.8	550.1
1990	25.0	6.0	136.9	1990	74.7	1.8	564.2
1991	26.5	6.0	147.0	1991	76.0	1.7	578.3
1992	28.1	6.0	157.6	1992	77.3	1.7	592.4
1993	29.8	6.0	168.9	1993	78.6	1.7	606.5
1994	31.6	6.0	180.9	1994	79.9	1.6	620.6
1995	33.5	6.0	193.6	1995	81.2	1.6	634.7
1996	35.5	6.0	207.1	1996	82.5	1.6	648.7
1997	37.6	6.0	221.4	1997	83.7	1.6	662.8
1998	39.9	6.0	236.5	1998	35.0	1.5	676.9
1999	42.3	6.0	252.6	1999	86.3	1.5	691.0
2000	44.9	6.0	269.6	2000	87.6	1.5	705.1

TABLE A3-54

Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
AFRICA				AFRICA			
Curve: 2 Index: .844849 Corrl: .890				Curve: 3 Index: .996996 Corrl: .890			
1968	$41.3		200.0	1968	$47.8		271.0
1969	41.8	1.2	205.5	1969	49.6	3.9	291.2
1970	42.3	1.1	210.7	1970	51.6	3.9	312.2
1971	42.7	1.1	215.7	1971	53.6	3.9	334.0
1972	43.2	1.0	220.5	1972	55.7	3.9	356.6
1973	43.6	1.0	225.2	1973	57.8	3.9	380.2
1974	44.0	1.0	229.8	1974	60.1	3.9	404.6
1975	44.4	.9	234.2	1975	62.4	3.9	430.0
1976	44.8	.9	238.5	1976	64.8	3.9	456.4
1977	45.2	.9	242.6	1977	67.3	3.9	483.8
1978	45.6	.8	246.7	1978	69.9	3.9	512.2
1979	45.9	.8	250.6	1979	72.6	3.9	541.8
1980	46.3	.8	254.5	1980	75.5	3.9	572.5
1981	46.6	.7	258.2	1981	78.4	3.9	604.4
1982	47.0	.7	261.9	1982	81.4	3.9	637.6
1983	47.2	.7	265.5	1983	84.6	3.9	672.0
1984	47.6	.7	269.0	1984	87.9	3.9	707.8
1985	47.9	.7	272.4	1985	91.3	3.9	744.9

TABLE A3-54 (Cont'd.)

AFRICA Curve: 2 Index: .844849 Corrl: .890				AFRICA Curve: 3 Index: .996996 Corrl: .890			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$48.2	.6	275.7	1986	$ 94.8	3.9	783.5
1987	48.5	.6	279.0	1987	98.5	3.9	823.6
1988	48.8	.6	282.2	1988	102.3	3.9	865.2
1989	49.1	.6	285.4	1989	106.3	3.9	908.5
1990	49.4	.6	288.5	1990	110.4	3.9	953.4
1991	49.7	.6	291.5	1991	114.7	3.9	1000.1
1992	50.0	.6	294.5	1992	119.1	3.9	1048.6
1993	50.2	.5	297.4	1993	123.8	3.9	1099.0
1994	50.5	.5	300.3	1994	128.6	3.9	1151.3
1995	50.7	.5	303.1	1995	133.5	3.9	1205.7
1996	51.0	.5	305.9	1996	138.7	3.9	1262.1
1997	51.3	.5	308.6	1997	144.1	3.9	1320.8
1998	51.5	.5	311.3	1998	149.7	3.9	1381.7
1999	51.7	.5	314.0	1999	155.5	3.9	1445.0
2000	52.0	.5	316.6	2000	161.5	3.9	1510.7

TABLE A3-55

	WEST COAST USA				WEST COAST USA		
	Curve: 1 Index: .968456 Corrl: .115				Curve: 2 Index: .864502 Corrl: .115		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$124.7		6218.8	1968	$109.4		6304.2
1969	128.8	3.3	6195.8	1969	111.1	1.5	6294.8
1970	132.9	3.2	6172.0	1970	112.7	1.5	6285.7
1971	137.0	3.1	6149.9	1971	114.3	1.4	6276.9
1972	141.1	3.0	6127.0	1972	115.8	1.3	6268.3
1973	145.2	2.9	6104.0	1973	117.3	1.3	6260.0
1974	149.3	2.8	6081.1	1974	118.8	1.2	6252.0
1975	153.4	2.7	6058.1	1975	120.1	1.2	6244.2
1976	157.5	2.7	6035.2	1976	121.5	1.1	6236.5
1977	161.6	2.6	6012.2	1977	122.8	1.1	6229.1
1978	165.7	2.5	5989.3	1978	124.1	1.1	6221.9
1979	169.8	2.5	5966.3	1979	125.4	1.0	6214.8
1980	173.9	2.4	5943.4	1980	126.6	1.0	6207.9
1981	178.0	2.4	5920.4	1981	127.8	1.0	6201.2
1982	182.1	2.3	5897.5	1982	129.0	.9	6194.6
1983	186.2	2.3	5874.5	1983	130.2	.9	6188.1
1984	190.3	2.2	5851.6	1984	131.3	.9	6181.8
1985	194.4	2.2	5828.6	1985	132.4	.8	6175.6

TABLE A3-55 (Cont'd.)

WEST COAST USA				WEST COAST USA			
Curve: 1 Index: .968456 Corrl: .115				Curve: 2 Index: .864502 Corrl: .115			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	198.4	2.1	5805.7	1986	133.5	.8	6196.5
1987	202.5	2.1	5782.7	1987	134.5	.8	6163.6
1988	206.6	2.0	5759.8	1988	135.6	.8	6157.7
1989	210.7	2.0	5736.8	1989	136.6	.8	6151.9
1990	214.8	1.9	5713.9	1990	137.6	.7	6146.3
1991	218.9	1.9	5690.9	1991	138.6	7	6140.7
1992	223.0	1.9	5668.0	1992	139.6	.7	6135.3
1993	227.1	1.8	5645.0	1993	140.6	.7	6129.9
1994	231.2	1.8	5622.1	1994	141.5	.7	6124.6
1995	235.3	1.8	5599.1	1995	142.4	.7	6119.4
1996	239.4	1.7	5576.2	1996	143.3	.6	6114.2
1997	243.5	1.7	5553.2	1997	144.3	.6	6109.2
1998	247.6	1.7	5530.3	1998	145.1	.6	6104.2
1999	251.7	1.7	5507.3	1999	146.0	.6	6099.3
2000	255.8	1.6	5484.4	2000	146.9	.6	6094.5

TABLE A3-56

	WEST COAST USA				WEST COAST CANADA		
	Curve: 3 Index: .990883 Corrl: .115				Curve: 1 Index. .939109 Corrl: .855		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$131.1		6183.1	1968	$14.1		5310.5
1969	137.5	4.9	6147.0	1969	14.6	3.1	5433.1
1970	144.3	4.9	6109.2	1970	15.0	3.0	5555.6
1971	151.3	4.9	6069.5	1971	15.5	2.9	5678.2
1972	158.8	4.9	6027.9	1972	15.9	2.8	5800.7
1973	166.6	4.9	5984.2	1973	16.3	2.8	5923.3
1974	174.8	4.9	5938.4	1974	16.8	2.7	6045.8
1975	183.3	4.9	5890.3	1975	17.2	2.6	6168.4
1976	192.3	4.9	5839.9	1976	17.6	2.5	6290.9
1977	201.8	4.9	5787.0	1977	18.1	2.5	6413.5
1978	211.7	4.9	5731.5	1978	18.5	2.4	6536.0
1979	222.1	4.9	5673.3	1979	19.0	2.4	6658.5
1980	233.0	4.9	5612.2	1980	19.4	2.3	6781.1
1981	244.4	4.9	5543.[illegible]	1981	19.8	2.3	6903.6
1982	255.5	4.9	5480.8	1982	20.3	2.2	7026.2
1983	269.1	4.9	5410.3	1983	20.7	2.2	7148.7
1984	282.3	4.9	5336.3	1984	21.1	2.1	7271.3
1985	296.1	4.9	5258.7	1985	21.6	2.1	7393.8

TABLE A3-56 (Cont'd)

WEST COAST USA				WEST COAST CANADA			
Curve: 3 Index .990883 Corrl: .115				Curve: 1 Index .939109 Corrl: .855			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	310.7	4.9	5177.2	1986	22.0	2.0	7516.4
1987	325.9	4.9	5091.7	1987	22.5	2.0	7638.9
1988	341.9	4.9	5002.1	1988	22.9	1.9	7761.5
1989	358.7	4.9	4908.0	1989	23.3	1.9	7884.0
1990	376.4	4.9	4809.4	1990	23.8	1.9	8006.8
1991	394.9	4.9	4705.8	1991	24.2	1.8	8129.1
1992	414.2	4.9	4597.2	1992	24.6	1.8	8251.7
1993	434.6	4.9	4483.3	1993	25.1	1.8	8374.2
1994	455.9	4.9	4363.7	1994	25.5	1.7	8496.8
1995	478.3	4.9	4238.3	1995	26.0	1.7	8619.3
1996	501.8	4.9	4106.8	1996	26.4	1.7	8741.8
1997	526.5	4.9	3968.7	1997	26.8	1.7	8864.4
1998	552.3	4.9	3823.9	1998	27.3	1.6	8986.9
1999	579.5	4.9	3672.0	1999	27.7	1.6	9109.5
2000	607.9	4.9	3512.6	2000	28.1	1.6	9232.0

TABLE A3-57

WEST COAST CANADA				WEST COAST CANADA			
Curve: 2 Index: .806685 Corrl: .855				Curve: 3 Index: .969837 Corrl: .855			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$12.4		4822.4	1968	$14.7		5462.5
1969	12.6	1.4	4869.6	1969	15.3	4.4	5644.9
1970	12.7	1.3	4915.2	1970	16.0	4.4	5835.4
1971	12.9	1.2	4959.1	1971	16.7	4.4	6034.3
1972	13.0	1.2	5001.7	1972	17.5	4.4	6242.1
1973	13.2	1.1	5042.8	1973	18.2	4.4	6459.1
1974	13.3	1.1	5082.8	1974	19.1	4.4	6685.7
1975	13.5	1.0	5121.5	1975	19.9	4.4	6922.4
1976	13.6	1.0	5159.2	1976	20.8	4.4	7169.5
1977	13.7	1.0	5195.9	1977	21.7	4.4	7427.7
1978	13.9	.9	5231.7	1978	22.7	4.4	7697.2
1979	14.0	.9	5266.5	1979	23.7	4.4	7978.8
1980	14.1	.9	5300.5	1980	24.7	4.4	8272.8
1981	14.2	.8	5333.7	1981	25.8	4.4	8579.9
1982	14.3	.8	5366.1	1982	27.0	4.4	8900.6
1983	14.5	.8	5397.8	1983	28.2	4.4	9235.5
1984	14.6	.8	5428.8	1984	29.4	4.4	9585.3
1985	14.7	.7	5459.2	1985	30.7	4.4	9950 6

TABLE A3-57 (Cont'd.)

	WEST COAST CANADA				WEST COAST CANADA		
	Curve: 2 Index: .806685 Corrl: .855				Curve: 3 Index: .969837 Corrl: .855		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$14.8	.7	5489.0	1986	$32.1	4.4	10332.1
1987	14.9	.7	5518.2	1987	33.5	4.4	10730.6
1988	15.0	.7	5546.8	1988	35.0	4.4	11146.7
1989	15.1	.7	5574.9	1989	36.5	4.4	11581.3
1990	15.2	.7	5602.5	1990	38.2	4.4	12035.1
1991	15.3	.6	5629.6	1991	39.9	4.4	12509.1
1992	15.4	.6	5656.2	1992	41.6	4.4	13004.1
1993	15.5	.6	5682.4	1993	43.5	4.4	13521.1
1994	15.6	.6	5708.1	1994	45.4	4.4	14061.0
1995	15.7	.6	5733.4	1995	47.4	4.4	14624.9
1996	15.7	.6	5758.3	1996	49.5	4.4	15213.8
1997	15.8	.6	5782.9	1997	51.7	4.4	15828.8
1998	15.9	.5	5807.0	1998	54.0	4.4	16471.1
1999	16.0	.5	5830.8	1999	56.4	4.4	17141.9
2000	16.1	.5	5854.3	2000	58.9	4.4	17842.4

TABLE A3-58

	WEST COAST CENTRAL AMERICA				WEST COAST CENTRAL AMERICA		
	Curve: 1 Index: .973394 Corrl: .917				Curve: 2 Index: .858997 Corrl: .917		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$27.3		1500.2	1968	$23.5		1256.2
1969	28.3	3.7	1565.7	1969	23.9	1.8	1284.3
1970	29.3	3.6	1631.1	1970	24.4	1.8	1311.5
1971	30.3	3.4	1696.5	1971	24.8	1.7	1338.0
1972	31.3	3.3	1761.9	1972	25.2	1.6	1363.6
1973	32.3	3.2	1827.3	1973	25.5	1.5	1388.6
1974	33.3	3.1	1892.7	1974	25.9	1.5	1412.8
1975	34.3	3.0	1958.1	1975	26.3	1.4	1436.5
1976	35.3	2.9	2023.5	1976	26.6	1.4	1459.6
1977	36.3	2.8	2088.9	1977	27.0	1.3	1482.1
1978	37.3	2.8	2154.3	1978	27.3	1.3	1504.2
1979	38.3	2.7	2219.7	1979	27.7	1.2	1525.7
1980	39.3	2.6	2285.2	1980	28.0	1.2	1546.8
1981	40.3	2.6	2350.6	1981	28.3	1.1	1567.5
1982	41.4	2.5	2416.0	1982	28.6	1.1	1587.7
1983	42.4	2.4	2481.4	1983	28.9	1.1	1607.6
1984	43.4	2.4	2540.8	1984	29.2	1.0	1627.0
1985	44.4	2.3	2612.2	1985	29.5	1.0	1646.2

TABLE A3-58 (Cont'd.)

WEST COAST CENTRAL AMERICA

Curve: 1 Index: .973394 Corrl: .917

Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$45.4	2.3	2677.6
1987	46.4	2.2	2743.0
1988	47.4	2.2	2808.4
1989	48.4	2.1	2873.8
1990	49.4	2.1	2939.3
1991	50.4	2.0	3004.7
1992	51.4	2.0	3070.1
1993	52.4	2.0	3135.5
1994	53.4	1.9	3200.9
1995	54.4	1.9	3266.3
1996	55.4	1.8	3331.7
1997	56.4	1.8	3397.1
1998	57.5	1.8	3462.5
1999	58.5	1.8	3527.9
2000	59.5	1.7	3593.3

WEST COAST CENTRAL AMERICA

Curve: 2 Index: .858997 Corrl: .917

Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$29.8	1.0	1664.9
1987	30.1	1.0	1683.4
1988	30.4	.9	1701.6
1989	30.6	.9	1719.4
1990	30.9	.9	1737.0
1991	31.2	.9	1754.3
1992	31.4	.8	1771.3
1993	31.7	.8	1788.1
1994	31.9	.8	1804.6
1995	32.2	.8	1820.9
1996	32.4	.8	1837.0
1997	32.7	.8	1852.8
1998	32.9	.7	1868.5
1999	33.2	.7	1883.9
2000	33.4	.7	1899.1

TABLE A3-59

	WEST COAST CENTRAL AMERICA				WEST COAST SOUTH AMERICA		
	Curve: 3 Index: .996763 Corrl: .917				Curve: 1 Index: .978017 Corrl: .811		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$29.3		1629.5	1968	$15.6		13472.5
1969	31.0	5.9	1742.1	1969	16.0	3.1	13896.1
1970	32.8	5.9	1861.5	1970	16.5	3.0	14319.6
1971	34.8	5.9	1987.8	1971	17.0	2.9	14743.1
1972	36.8	5.9	2121.7	1972	17.5	2.8	15166.7
1973	39.0	5.9	2263.5	1973	18.0	2.8	15590.2
1974	41.3	5.9	2413.7	1974	18.5	2.7	16013.7
1975	43.8	5.9	2572.7	1975	18.9	2.6	16437.3
1976	46.4	5.9	2741.2	1976	19.4	2.6	16860.8
1977	49.1	5.9	2919.7	1977	19.9	2.5	17284.3
1978	52.0	5.9	3108.8	1978	20.4	2.4	17707.9
1979	55.1	5.9	3309.0	1979	20.9	2.4	18131.4
1980	58.4	5.9	3521.2	1980	21.4	2.3	18554.9
1981	61.8	5.9	3745.9	1981	21.8	2.3	18978.5
1982	65.5	5.9	3983.8	1982	22.3	2.2	19402.0
1983	69.4	5.9	4235.9	1983	22.8	2.2	19825.6
1984	73.5	5.9	4503.0	1984	23.3	2.1	20249.1
1985	77.8	5.9	4785.8	1985	23.8	2.1	20672.6

TABLE A3-59 (Cont'd)

	WEST COAST CENTRAL AMERICA				WEST COAST SOUTH AMERICA		
	Curve: 3 Index: .996763 Corrl: .917				Curve: 1 Index: .978017 Corrl: .811		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$ 82.4	5.9	5085.4	1986	$24.3	2.0	21096.2
1987	87.3	5.9	5402.7	1987	24.7	2.0	21519.7
1988	92.5	5.9	5738.9	1988	25.2	2.0	21943.2
1989	98.0	5.9	6094.9	1989	25.7	1.9	22366.8
1990	103.8	5.9	6472.1	1990	26.2	1.9	22790.3
1991	109.9	5.9	6871.5	1991	26.7	1.8	23213.8
1992	116.4	5.9	7294.7	1992	27.2	1.8	23637.4
1993	123.3	5.9	7742.9	1993	27.6	1.8	24060.9
1994	130.6	5.9	8217.6	1994	28.1	1.7	24484.4
1995	138.3	5.9	8720.5	1995	28.6	1.7	24908.0
1996	146.5	5.9	9253.2	1996	29.1	1.7	25331.5
1997	155.2	5.9	9817.4	1997	29.6	1.7	25755.0
1998	164.4	5.9	10415.0	1998	30.1	1.6	26178.6
1999	174.2	5.9	11048.0	1999	30.5	1.6	26602.1
2000	184.5	5.9	11718.6	2000	31.0	1.6	27025.7

TABLE A3-60

	WEST COAST SOUTH AMERICA Curve: 2 Index: .861060 Corrl: .811				WEST COAST SOUTH AMERICA Curve: 3 Index: .995123 Corrl: .811		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$13.7		11889.0	1968	$16.3		14087.5
1969	13.9	1.4	12059.6	1969	17.0	4.5	14732.3
1970	14.1	1.3	12224.1	1970	17.8	4.5	15406.2
1971	14.3	1.3	12383.0	1971	18.6	4.5	16110.7
1972	14.5	1.2	12536.8	1972	19.4	4.5	16847.1
1973	14.7	1.2	12685.8	1973	20.3	4.5	17616.8
1974	14.8	1.1	12830.3	1974	21.2	4.5	18421.3
1975	15.0	1.1	12970.7	1975	22.2	4.5	19262.3
1976	15.1	1.0	13107.2	1976	23.2	4.5	20141.4
1977	15.3	1.0	13240.2	1977	24.2	4.5	21060.3
1978	15.4	1.0	13369.7	1978	25.3	4.5	22020.8
1979	15.6	.9	13496.0	1979	26.3	4.5	23024.7
1980	15.7	.9	13619.3	1980	27.7	4.5	24074.1
1981	15.9	.9	13739.7	1981	28.9	4.5	25171.1
1982	16.0	.8	13857.5	1982	30.2	4.5	26317.7
1983	16.1	.8	13972.6	1983	31.6	4.5	27516.2
1984	16.3	.8	14085.4	1984	33.0	4.5	28769.0
1985	16.4	.8	14195.8	1985	34.5	4.5	30078.5

TABLE A3-60 (Cont'd.)

WEST COAST SOUTH AMERICA				WEST COAST SOUTH AMERICA			
Curve: 2 Index: .861060 Corrl: .811				Curve: 3 Index: .995123 Corrl: .811			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$16.5	.8	14304.0	1986	$36.1	4.5	31447.3
1987	16.6	.7	14410.1	1987	37.7	4.5	32878.0
1988	16.7	.7	14514.3	1988	39.4	4.5	34373.6
1989	16.9	.7	14616.5	1989	41.2	4.5	35939.8
1990	17.0	.7	14716.8	1990	43.1	4.5	37570.9
1991	17.1	.7	14815.4	1991	45.0	4.5	39278.9
1992	17.2	.6	14912.3	1992	47.1	4.5	41064.3
1993	17.3	.6	15007.6	1993	49.2	4.5	42930.5
1994	17.4	.6	15101.3	1994	51.4	4.5	44881.2
1995	17.5	.6	15193.5	1995	53.7	4.5	46920.2
1996	17.6	.6	15284.3	1996	56.2	4.5	49051.5
1997	17.7	.6	15373.7	1997	58.7	4.5	51279.3
1998	17.8	.6	15461.8	1998	61.4	4.5	53608.1
1999	17.9	.6	15548.5	1999	64.1	4.5	56042.2
2000	18.0	.5	15634.0	2000	67.1	4.5	58586.5

TABLE A3-61

Fiscal Year	OCEANIA Curve: 1 Index: .969782 Corrl: .872 GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	OCEANIA Curve: 2 Index: .821438 Corrl: .872 GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$29.5		2623.4	1968	$26.1		2344.3
1969	30.4	3.0	2694.6	1969	26.4	1.3	2371.7
1970	31.3	2.9	2765.8	1970	26.7	1.2	2398.1
1971	32.1	2.8	2837.0	1971	27.0	1.2	2423.6
1972	33.0	2.7	2908.2	1972	27.3	1.1	2448.3
1973	33.9	2.7	2979.4	1973	27.6	1.1	2472.1
1974	34.8	2.6	3050.6	1974	27.9	1.0	2495.2
1975	35.7	2.5	3121.8	1975	28.2	1.0	2517.6
1976	36.5	2.5	3193.0	1976	28.5	1.0	2539.4
1977	37.4	2.4	3264.2	1977	28.7	.9	2560.6
1978	38.3	2.3	3335.3	1978	29.0	.9	2581.2
1979	39.2	2.3	3406.5	1979	29.2	.9	2601.3
1980	40.1	2.2	3477.7	1980	29.5	.8	2620.9
1981	40.9	2.2	3548.9	1981	29.7	.8	2640.1
1982	41.8	2.1	3620.1	1982	29.9	.8	2658.8
1983	42.7	2.1	3691.3	1983	30.2	.8	2677.1
1984	43.6	2.1	3762.5	1984	30.4	.7	2695.0
1985	44.5	2.0	3833.7	1985	30.6	.7	2712.5

TABLE A3-61 (Cont'd)

	OCEANIA				OCEANIA		
	Curve: 1 Index: .969782 Corrl: .872				Curve: 2 Index: .821438 Corrl: .872		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$45.3	2.0	3904.9	1986	$30.8	.7	2729.6
1987	46.2	1.9	3976.1	1987	31.0	.7	2746.4
1988	47.1	1.9	4047.3	1988	31.2	.7	2762.9
1989	48.0	1.9	4118.5	1989	31.4	.6	2779.0
1990	48.8	1.8	4189.7	1990	31.6	.6	2794.9
1991	49.7	1.8	4260.9	1991	31.8	.6	2810.5
1992	50.6	1.8	4332.1	1992	32.0	.6	2825.8
1993	51.5	1.7	4403.3	1993	32.2	.6	2840.8
1994	52.4	1.7	4474.5	1994	32.4	.6	2855.6
1995	53.2	1.7	4545.7	1995	32.6	.6	2870.1
1996	54.1	1.7	4616.9	1996	32.7	.5	2884.4
1997	55.0	1.6	4688.0	1997	32.9	.5	2898.5
1998	55.9	1.6	4759.2	1998	33.1	.5	2912.3
1999	56.8	1.6	4830.4	1999	33.2	.5	2926.0
2000	57.6	1.5	4901.6	2000	33.4	.5	2939.4

TABLE A3-62

	OCEANIA				JAPAN		
	Curve: 3 Index: .988992 Corrl: .872				Curve: 1 Index: .938911 Corrl: .922		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U. S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$30.6		2715.0	1968	$101.4		3697.9
1969	31.9	4.2	2820.1	1969	106.3	4.8	3937.0
1970	33.3	4.2	2929.5	1970	111.2	4.6	4176.2
1971	34.7	4.2	3043.6	1971	116.1	4.4	4415.3
1972	36.2	4.2	3162.6	1972	121.0	4.2	4654.5
1973	37.7	4.2	3286.6	1973	125.8	4.0	4893.6
1974	39.3	4.2	3415.8	1974	130.7	3.9	5132.7
1975	41.0	4.2	3550.5	1975	135.6	3.7	5371.9
1976	42.7	4.2	3690.9	1976	140.5	3.6	5611.0
1977	44.5	4.2	3837.2	1977	145.4	3.5	5850.2
1978	46.4	4.2	3989.7	1978	150.3	3.4	6089.3
1979	48.3	4.2	4148.7	1979	155.1	3.2	6328.4
1980	50.4	4.2	4314.4	1980	160.0	3.1	6567.6
1981	52.5	4.2	4487.1	1981	164.9	3.1	6806.7
1982	54.7	4.2	4667.1	1982	169.8	3.0	7045.9
1983	57.1	4.2	4854.8	1983	174.7	2.9	7285.0
1984	59.5	4.2	5050.3	1984	179.5	2.8	7524.1
1985	62.0	4.2	5254.2	1985	184.4	2.7	7763.3

TABLE A3-62 (Cont'd.)

	OCEANIA				JAPAN		
	Curve: 3 Index: .988992 Corrl: .872				Curve: 1 Index: .938911 Corrl: .922		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	64.6	4.2	5466.7	1986	189.3	2.6	8002.4
1987	67.3	4.2	5693.2	1987	194.2	2.6	8241.6
1988	70.2	4.2	5919.0	1988	199.1	2.5	8480.7
1989	73.2	4.2	6159.6	1989	203.9	2.5	8719.8
1990	76.3	4.2	6410.4	1990	208.8	2.4	8959.0
1991	79.5	4.2	6671.9	1991	213.7	2.3	9198.1
1992	82.9	4.2	6944.3	1992	218.6	2.3	9437.2
1993	86.4	4.2	7228.4	1993	223.5	2.2	9676.4
1994	90.0	4.2	7524.4	1994	228.3	2.2	9915.5
1995	93.8	4.2	7832.9	1995	233.2	2.1	10154.7
1996	97.8	4.2	8154.6	1996	238.1	2.1	10393.8
1997	101.9	4.2	8489.8	1997	243.0	2.0	10632.9
1998	106.2	4.2	8839.2	1998	247.9	2.0	10872.1
1999	110.7	4.2	9203.4	1999	252.7	2.0	11111.2
2000	115.4	4.2	9583.0	2000	257.6	1.9	11350.4

TABLE A3-63

	JAPAN				JAPAN		
	Curve: 2 Index: .829771 Corrl: .922				Curve: 3 Index: .993740 Corrl: .922		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$ 82.0		2746.6	1968	$116.8		4449.0
1969	84.4	2.9	2862.1	1969	127.9	9.5	4993.0
1970	86.7	2.7	2975.1	1970	140.0	9.5	5588.8
1971	89.0	2.6	3085.8	1971	153.4	9.5	6241.2
1972	91.2	2.5	3194.2	1972	167.9	9.5	6955.7
1973	93.3	2.4	3300.5	1973	183.9	9.5	7738.0
1974	95.5	2.3	3404.8	1974	201.4	9.5	8594.8
1975	97.6	2.2	3507.3	1975	220.5	9.5	9533.1
1976	99.6	2.1	3608.0	1976	241.5	9.5	10560.5
1977	101.6	2.0	3707.1	1977	264.5	9.5	11685.6
1978	103.6	2.0	3804.6	1978	289.6	9.5	12917.7
1979	105.6	1.9	3900.6	1979	317.1	9.5	14267.0
1980	107.5	1.8	3995.2	1980	347.3	9.5	15744.6
1981	109.4	1.8	4088.5	1981	380.3	9.5	17362.6
1982	111.3	1.7	4180.4	1982	416.5	9.5	19134.5
1983	113.1	1.7	4271.1	1983	456.1	9.5	21074.9
1984	115.0	1.6	4360.6	1984	499.4	9.5	23199.7
1985	116.8	1.6	4449.0	1985	546.9	9.5	25526.6

TABLE A3-63 (Cont'd.)

	JAPAN				JAPAN		
	Curve: 2 Index: .829771 Corrl: .922				Curve: 3 Index: .993740 Corrl: .922		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$118.6	1.5	4536.3	1986	$ 598.9	9.5	28074.7
1987	120.3	1.5	4622.5	1987	655.9	9.5	30865.1
1988	122.1	1.4	4707.8	1988	718.2	9.5	33920.8
1989	123.8	1.4	4792.0	1989	786.5	9.5	37267.1
1990	125.5	1.4	4875.4	1990	861.3	9.5	40931.5
1991	127.2	1.3	4957.8	1991	943.2	9.5	44944.3
1992	128.8	1.3	5039.3	1992	1032.9	9.5	49338.7
1993	130.5	1.3	5120.0	1993	1131.1	9.5	54150.9
1994	132.1	1.2	5199.9	1994	1238.6	9.5	59420.6
1995	133.7	1.2	5279.0	1995	1356.4	9.5	65191.4
1996	135.3	1.2	5357.3	1996	1485.4	9.5	71510.9
1997	136.9	1.2	5434.9	1997	1626.6	9.5	78431.2
1998	138.5	1.1	5511.8	1998	1781.3	9.5	86009.5
1999	140.0	1.1	5587.9	1999	1950.6	9.5	94308.4
2000	141.6	1.1	5663.4	2000	2136.1	9.5	103396.4

TABLE A3-64

	ASIA (LESS JAPAN) Curve: 1 Index: .968921 Corrl: .881				ASIA (LESS JAPAN) Curve: 2 Index: .848461 Corrl: .881		
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$33.0		2553.4	1968	$29.0		2292.5
1969	34.1	3.2	2621.6	1969	29.4	1.5	2319.8
1970	35.2	3.1	2689.7	1970	29.8	1.4	2346.2
1971	36.2	3.0	2757.9	1971	30.2	1.3	2371.7
1972	37.3	2.9	2826.1	1972	30.6	1.3	2396.4
1973	38.4	2.9	2894.3	1973	31.0	1.2	2420.3
1974	39.4	2.8	2962.5	1974	31.3	1.2	2443.6
1975	40.5	2.7	3030.6	1975	31.7	1.1	2466.2
1976	41.6	2.6	3098.8	1976	32.0	1.1	2488.1
1977	42.6	2.6	3167.0	1977	32.4	1.0	2509.5
1978	43.7	2.5	3235.2	1978	32.7	1.0	2530.4
1979	44.8	2.4	3303.4	1979	33.0	1.0	2550.7
1980	45.8	2.4	3371.6	1980	33.3	.9	2570.6
1981	46.9	2.3	3439.7	1981	33.6	.9	2590.0
1982	48.0	2.3	3507.9	1982	33.9	.9	2609.0
1983	49.0	2.2	3576.1	1983	34.2	.9	2627.6
1984	50.1	2.2	3644.3	1984	34.5	.8	2645.8
1985	51.1	2.1	3712.5	1985	34.8	.8	2663.6

TABLE A3-64 (Cont'd.)

ASIA (LESS JAPAN)				ASIA (LESS JAPAN)			
Curve: 1 Index: .968921 Corrl: .881				Curve: 2 Index: .848461 Corrl: .881			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)	Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	52.2	2.1	3780.6	1986	35.0	.8	2681.1
1987	53.3	2.0	3848.8	1987	35.3	.8	2698.2
1988	54.3	2.0	3917.0	1988	35.6	.7	2715.0
1989	55.4	2.0	3985.2	1989	35.8	.7	2731.6
1990	56.5	1.9	4053.4	1990	36.1	.7	2747.8
1991	57.5	1.9	4121.5	1991	36.3	.7	2763.7
1992	58.6	1.9	4189.7	1992	36.6	.7	2779.4
1993	59.7	1.8	4257.9	1993	36.8	.7	2794.8
1994	60.7	1.8	4326.1	1994	37.0	.6	2810.0
1995	61.8	1.8	4394.3	1995	37.3	.6	2824.9
1996	62.9	1.7	4462.4	1996	37.5	.6	2839.6
1997	63.9	1.7	4530.6	1997	37.7	.6	2854.1
1998	65.0	1.7	4598.8	1998	38.0	.6	2868.3
1999	66.1	1.6	4667.0	1999	38.2	.6	2882.4
2000	67.1	1.6	4735.2	2000	38.4	.6	2896.3

TABLE A3-65

ASIA (LESS JAPAN)			
Curve: 3 Index: .995555 Corri: .881			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1968	$34.6		2653.5
1969	36.2	4.8	2758.8
1970	38.0	4.8	2869.2
1971	39.8	4.8	2984.7
1972	41.7	4.8	3105.8
1973	43.7	4.8	3232.7
1974	45.7	4.8	3365.5
1975	47.9	4.8	3504.7
1976	50.2	4.8	3650.5
1977	52.6	4.8	3803.3
1978	55.1	4.8	3963.3
1979	57.7	4.8	4130.9
1980	60.4	4.8	4306.5
1981	63.3	4.8	4490.4
1982	66.3	4.8	4683.1
1983	69.5	4.8	4885.0
1984	72.8	4.8	5096.5
1985	76.2	4.8	5318.0

TABLE A3-65 (Cont'd.)

ASIA (LESS JAPAN)			
Curve: 3 Index: .995555 Corrl: .881			
Fiscal Year	GNP Forecast (1967 U.S. Billion $)	Percent Change	Origin Cargo Forecast (000 Long Tons)
1986	$ 79.9	4.8	5550.0
1987	83.7	4.8	5793.1
1988	87.6	4.8	6047.8
1989	91.8	4.8	6314.5
1990	96.2	4.8	6594.0
1991	100.7	4.8	6886.7
1992	105.5	4.8	7193.4
1993	110.6	4.8	7514.6
1994	115.8	4.8	7851.1
1995	121.3	4.8	8203.7
1996	127.1	4.8	8573.0
1997	133.1	4.8	8959.8
1998	139.5	4.8	9365.1
1999	146.1	4.8	9789.6
2000	153.1	4.8	10234.4

TABLE A3-66

INDEXES AND EQUATION COEFFICIENTS
FOR REGIONAL PRODUCT VS. TIME

Region	Curve Type	Index	A	B
West Indies	1	.995561	2.975163	.315480
	2	.926643	2.773667	.359228
	3	.979622	3.385464	.055477
East Coast USA	1	.931883	325.452941	15.343550
	2	.792589	313.948521	.193595
	3	.960518	342.603778	.032010
Europe	1	.989162	225.116993	17.855521
	2	.875949	215.291518	.285921
	3	.997958	248.303594	.045838
East Coast Canada	1	.962808	17.512418	1.157172
	2	.859973	16.705058	.253069
	3	.981640	18.946311	.040611
East Coast Central America	1	.973394	8.145752	1.006295
	2	.858997	8.249667	.355673
	3	.996763	9.802556	.057546
East Coast South America	1	.993088	23.531373	1.861610
	2	.881609	22.287505	.289983
	3	.992185	25.826647	.046206
Asia Minor – Middle East	1	.959059	1.839216	.241486
	2	.833157	1.912783	.357850
	3	.990402	2.260092	.058602
Africa	1	.980297	21.669281	1.293292
	2	.844849	20.775662	.233249
	3	.996996	23.193547	.038056

TABLE A3-66

INDEXES AND EQUATION COEFFICIENTS FOR REGIONAL PRODUCT VS. TIME (Cont'd.)

Region	Curve Type	Index	A	B
West Coast USA	1	.968456	46.817647	4.098142
	2	.864502	45.476841	.298190
	3	.990883	52.699722	.047950
West Coast Canada	1	.939109	5.825490	.437668
	2	.806685	5.705498	.263576
	3	.969837	6.436578	.043408
West Coast Central America	1	.973394	8.145752	1.006295
	2	.858997	8.249667	.355673
	3	.996763	9.802556	.057546
West Coast South America	1	.978017	6.367974	.483488
	2	.861060	6.130538	.274248
	3	.995123	7.008477	.044282
Oceania	1	.969782	12.811111	.878947
	2	.821438	12.430203	.251489
	3	.988992	13.941702	.041447
Japan	1	.938911	3.710608	4.880392
	2	.829771	16.120274	.552579
	3	.993740	20.790857	.090828
Asia (less Japan)	1	.968921	12.796078	1.065325
	2	.848461	12.491271	.285590
	3	.995555	14.311547	.046465

Curve Type (1) one is expressed as $Y = A + Bx$
Curve Type (2) two as $Y = Ax^{B}$
Curve Type (3) three as $Y = Ae^{BX}$
(The letter "e" stands for the base of the natural logarithm, 2.718...)

TABLE A3-67

LOW CARGO TONNAGE FORECAST BASED ON SEPARATE FORECASTS OF JAPAN TRADE AND OTHER COMMERCIAL CARGO

Quantities in Millions of Long Tons in Year

Year	Commercial Cargo Traffic A	B	A+B	C	A+B+C	Other Traffic D	Total Traffic
1950	26.0	2.3	28.3	–	28.3	1.5	29.8
1955	25.2	5.2	40.4	–	40.4	0.9	41.3
1960	44.5	14.4	58.9	–	58.9	1.1	60.0
1965	53.7	23.3	77.0	–	77.0	2.4	79.4
1970	63.0	41.5	104.5	–	104.5	7.0	111.5
1975	72.2	62.5	134.7	3.4	138.1	3.0	141.1
1980	81.5	79.7	161.2	8.1	169.3	2.0	171.3
1985	90.7	90.3	181.0	13.6	194.6	2.5	197.1
1990	100.0	95.5	195.5	19.6	215.1	3.0	218.1
1995	109.2	98.1	207.3	25.9	233.2	3.5	236.7
2000	118.5	99.2	217.7	32.6	250.3	4.0	254.3
2005	127.7	99.8	227.5	39.8	267.3	4.5	271.8
2010	137.0	100.0	237.0	47.5	284.5	5.0	289.5
2015	146.2	100.0	246.2	55.5	301.7	5.5	307.2
2020	155.5	100.0	255.5	63.9	319.4	6.0	325.4
2025	164.7	100.0	264.7	72.7	337.4	6.5	343.9
2030	174.0	100.0	274.0	82.2	356.2	7.0	363.2
2035	183.2	100.0	283.2	92.0	375.2	7.5	382.7
2040	192.5	100.0	292.5	102.5	395.0	8.0	403.0

A: Trend of growth of all commercial traffic except shipments to and from Japan $A = 24.10 + 1.85\ (\text{Year} - 1949)$

B: Trend of growth of shipments to and from Japan $B = 100 \div 1.0 + \log^{-1}\left(\frac{\text{Year} - 1972}{13.5}\right)$

C: Allowance for unforeseeable growth trends $C = .005\ (\text{Year} - 1970) \times (A+B)$

D: Non-commercial traffic as classified by Panama Canal Company, approximately 2% of commercial cargo under normal conditions.

Appendix 4

HARBOR AND PORT DEVELOPMENT

Introduction

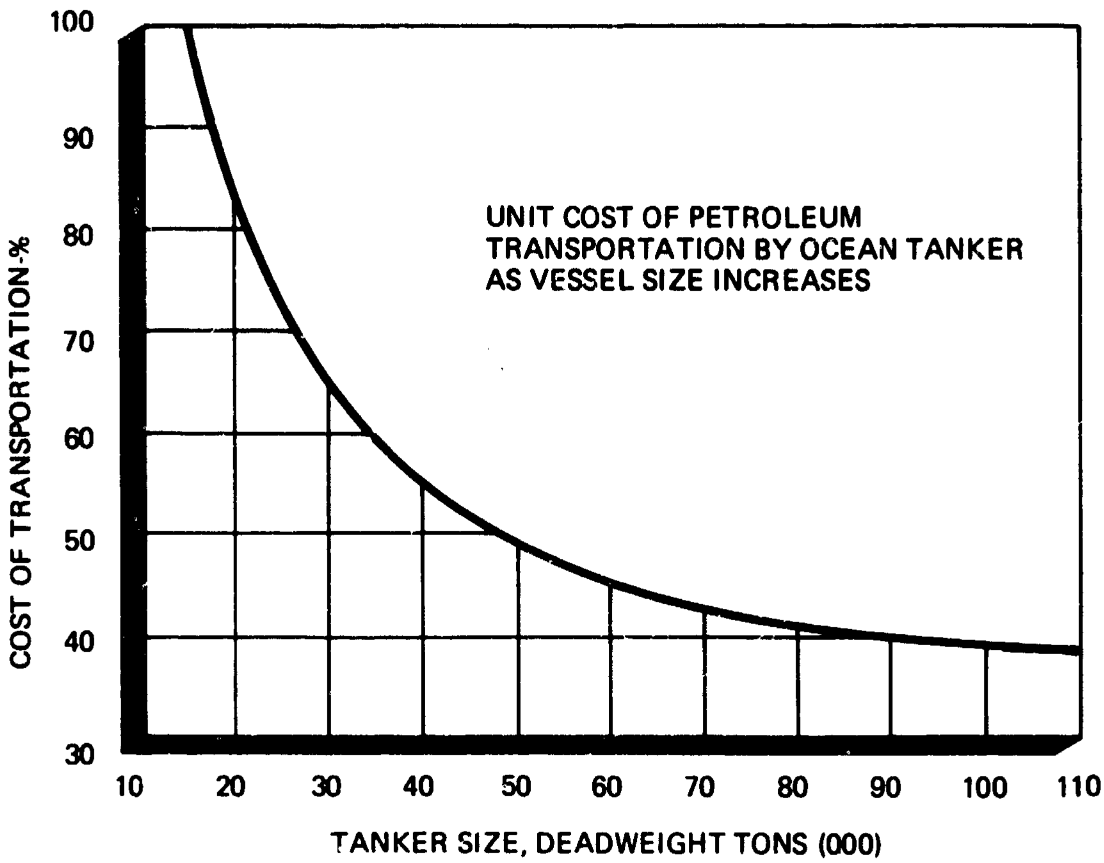
The increasing volume of production of raw materials to meet the demands of growing markets and increasing distances of transportation have already brought about great increases in the unit size of carriers and renovation and extensions of shipbuilding facilities. The next evolution to be expected is the renovation and modernization of port and harbor facilities, the construction of offshore facilities, and the deepening of waterways to accommodate these larger carriers. The economies of scale of the super ships in the transport of dry bulk and liquid cargoes are such that the provision of terminal facilities for them near the sources and destinations of such cargoes is inevitable. This trend to deep ports is already well advanced throughout the world, and the pressures are mounting in the United States for greater activity in this field.

Transport Cost Implications

The following Figure A4-1 illustrates the startling economies in the unit cost of transporting petroleum made possible by an increase in vessel scale. A specific example of transport savings made possible by supertankers is the recently initiated movement of bulk petroleum from the Persian Gulf to Bantry Bay, Ireland, by the way of the Cape of Good Hope using 326,000 DWT vessels. Although the route is 13,000 miles longer than the Suez Canal route, the operating cost per barrel of petroleum is estimated to be half the operating cost of transporting the petroleum through the Suez Canal in 50,000 DWT ships. The economies of large scale ships are applicable to the dry bulker and freighter classes but to a lesser scale because of the smaller ships in these classes. For example, Japan is now using 150,000 DWT bulk carriers to transport combined coal and ore cargoes from the United States and Brazil to Japan via the Cape of Good Hope at a considerable savings over the cost of transport of these same commodities in 65,000 DWT ships via the much shorter Panama Canal route. The savings are estimated to be 30% greater than the cost of Panama Canal tolls, indicating that economies of scale rather than tolls are the determinant in the choice of the longer route.

Harbors of the World

Japan's plans for future harbor construction include projects for establishing 4 or 5 central terminal stations for tankers, each one of which apparently would serve a region. Tankers up to 300,000 DWT are considered. To receive coal and ore for the Japanese steel industry which is located mostly with direct access to the sea, the country plans to have 27



SOURCE: DEPARTMENT OF ARMY, CORPS OF ENGINEERS, TOTAL UNIT OPERATING COSTS OF A T-2 TANKER, INCLUDING CAPITAL COSTS, WERE TAKEN AS EQUIVALENT TO 100 PERCENT. COSTS FOR LARGER VESSELS ARE RELATED TO THIS AS A PERCENT OF THE T-2 COSTS

RELATIONSHIP OF TRANSPORT OPERATING COST TO TANKER SIZE

FIGURE A4-1

special wharves to accommodate carriers of 50,000 DWT and more. Five would be capable of receiving vessels of 110,000 to 130,000 DWT.

A transshipment station for Europe's Atlantic seaboard is in operation at Bantry Bay, Ireland. The station receives 326,000 DWT tankers loaded in the Persian Gulf. Existing facilities in the loading area were updated and reconstructed to accommodate this trade.

Plans have been announced by the Mersey Docks and Harbour Board for the construction of an artificial island 11 miles off the coast of Wales, in Liverpool Bay, which would consist of an insular breakwater structure upon which a series of massive oil storage tanks will be linked to the mainland by underwater pipelines. The island unloading facility could become one of the most important crude oil transshipment stations in Europe, accommodating mammoth tankers up to 1,000,000 DWT.

In Western Europe, six ports are being enlarged to capture as great a share as possible of the expanding international trade to and from Europe. The ports are Rotterdam and Amsterdam in the Netherlands, Antwerp in Belgium, and Marseilles, Le Havre and Dunkirk in France. All are committed to large development projects to accommodate the large tankers and bulk carriers now coming into service and to accommodate container transport.

The port of Dunkirk plans to build an artificial, U-shaped island about eight miles offshore to the west of the French port, in the Strait of Dover, to accommodate tankers of 500,000 to 750,000 DWT. The island terminal would be a principal tanker unloading facility and transshipment station connected to the mainland by submerged crude oil pipelines.

One harbor official expressed his views as follows: "This is nothing short of a maritime marathon. The port which expands first will get the business of the future; the ones which don't do anything will get nothing. And all the big ones are out to win the gold medal." The ultimate solution may be one of cooperation within the Common Market concept rather than competition among the ports, with a regional harbor to serve the needs of the area regardless of national boundaries and local economies.

World Waterways

There are certain sea areas through which large tankers will be unable to pass. Considered impassable for ships drawing 66 to 82 feet of water (requiring 82 feet to 100 feet of depth) are the following areas:

a. River Plate Estuary including Montevideo and Buenos Aires.
b. Large areas of the White Sea, including Archangel.
c. Baltic Sea.
d. Southern part of the North Sea, including Dogger Bank.
e. Shallow coastal areas around the world, the English Channel, the approaches to the Black Sea and to New York.

Ship Sizes in Future U.S. Ocean Trade

The growth of tankers, the fastest growing type of all ship types, has been accommodated by development of offshore terminals and new deepwater terminals located away from traditional and established ports. By 2000, crude oil tankers ranging from 150,000 to 200,000 DWT are expected to be operating in the U.S. Atlantic Coast, Gulf-Mideast trade, and from Alaska if the Northwest Passage proves navigable. Larger

TABLE A4-1

CAPACITY OF SOME MAJOR EUROPEAN PORTS

Port	Ship Capacity in DWT Present	Ultimate
Trieste (Muggia Bay)	160,000 DWT	Dredging for 200,000 DWT under consideration
Genoa	100,000 DWT in 1968	–
Naples	--	250,000 DWT
Marseilles	120,000 DWT	200,000 DWT
Bilbao, Spain	–	500,000 DWT (potential)
LeHavre	120,000 DWT	–
Dunkirk	100,000 DWT	125,000 DWT by 1970 250,000 DWT later
Rotterdam (Europort)	200,000 DWT	250,000 DWT in 1969 500,000 DWT ultimate
London	90,000 DWT	–
Milford Haven	100,000 DWT	175,000 DWT
Liverpool	100,000 DWT	Dredging for 150,000 DWT
Southhampton	100,000 DWT	–
Immingham	100,000 DWT	–
Glasgow	100,000 DWT	200,000 DWT in 1969 500,000 DWT possible
Antwerp	60,000 DWT	–
Hamburg	65,000 DWT	Plans for 82' depth
Gothenburg	100,000 DWT	200,000 DWT in 1969

vessels may also be in use, but their numbers are expected to be few, and limited to serving very specialized ports. In the U.S. Atlantic and Gulf-Caribbean trade, the vessels will probably range from 80,000 DWT to 150,000 DWT. The Alaska-West Coast trade will probably use ships of this size in the latter group. These ships will not be intended to enter most of the established U.S. ports.

Petroleum product carriers are not expected to exceed 80,000 DWT and most will average 40,000 DWT or less. These vessels will draw 42 to 49 feet fully loaded and can be operated in and out of some major Atlantic and Gulf and few West Coast petroleum ports. Because of the number and complexity of products carried, the product carriers must generally reach existing distribution terminals located at historic ports accessible by means of traditional channels. Alternatives used for crude carriers are not feasible in this trade.

Dry bulk carriers operate over a much greater variety of routes and carry a much greater variety of cargoes, none of which are available in as great a volume as crude oil. To maximize operational flexibility under these circumstances, dry bulkers will be built to smaller sizes than tankers. The industries served by dry bulkers will probably remain close to traditional harbor areas because the industries are difficult to relocate, and because the new handling methods, transshipment and distribution solutions available to the oil industry are not available to the dry bulk consuming industry. For these reasons, dry bulkers will generally continue to use historic United States harbors. Until deeper ports are provided, dry bulk carriers will range from 50,000 DWT to 75,000 DWT, with a few specialized ships, as for iron ore, up to 100,000 DWT.

Oil-bulk-ore (OBO) carriers are more closely allied to the crude oil tanker and could reach 200,000 to 250,000 DWT. These could enter U.S. harbors only partially loaded.

The recent Arctic oil discoveries on the north slope of Alaska, coupled with the current Federal investigation of the future need of our present oil import quota system, may provide future economic incentives to employ tankers larger than 250,000 DWT on the long haul crude oil routes from Alaska and the Middle East to U.S. Atlantic and Gulf ports. For example, current vessel sizes being considered for the Alaskan oil movement are in the 225,000 to 275,000 DWT range. If these prove successful, this could influence operators in the U.S. Atlantic and Gulf–Mideast trade to also use larger vessel sizes.

Considering the existing physical and economic limitations of dredging U.S. harbors and channels to greater depths appropriate to accommodate future dry and liquid bulk carriers, it will be necessary to construct some offshore terminal facilities as a reasonable alternative. With appropriately designed U.S. offshore petroleum handling systems, tanker operators in the aforementioned trades will utilize the largest size tankers, in relation to operating costs and total distance, which will supply the necessary transport requirements of each route in the most economical manner.

The technique of handling powdered dry bulk materials as a liquid slurry is already in use on a limited scale in the transport of coal. While this method does not appear likely to replace dry handling of many types of bulk materials, it offers the distinct possibility that relatively inexpensive off-shore petroleum terminals can be adapted to handle ore and coal in slurry form. If this proves feasible, these materials will move in the same sizes of superships that now carry petroleum.

General cargo vessels will remain closely oriented to traditional harbors, the available shoreside space, and the existing land transportation even more than the dry bulkers. These

factors will restrain general cargo vessel sizes. Another restraint is the greater need for frequent service afforded by smaller ships compared with the less frequent sailing of a larger ship which would provide less expensive service. The largest general cargo vessels in 2000 are estimated to be 950 feet to 1,000 feet long, 110 to 115 feet in beam and drawing 33 to 35 feet when fully loaded.

In summary, crude oil, oil-bulk ore and certain dry bulk carriers are the types posing serious problems for existing U.S. harbors. The main problem concerns water depths, and to a lesser extent, horizontal waterway dimensions. Ships larger than 200,000 to 250,000 DWT class probably will not appear in U.S. oceanborne trade by 2000, except possibly to serve a very small number of highly specialized ports.

Ship Characteristics

The ship characteristic which most frequently excludes large ships from existing harbors is the vessel draft. The average draft for tankers and dry bulkers up to the projected maximum sizes are shown on Fig. A4-2. Drafts of individual ships vary from these average values. Freighters are expected to draw 40 feet or less, even at the largest projected size. Ships often use the full depths available in harbors or channels, occasionally taking advantage of the high tide to permit entrance where entrance at low tide is not possible.

Harbor and Channel Depths

During the 1940's the T-2 tanker (16,600 DWT) was used as the criterion in determining that a depth of 35 feet was required at the major United States ports. Tankers of 35,000 DWT required 40-foot depths and necessitated further enlargement of harbors and channels. Most of the major United States harbors are less than 42 feet deep at the present time and only at three port locations can a vessel in the 100,000 DWT size range be fully loaded at berth. These are the petroleum berths at Los Angeles and Long Beach and a grain berth at Seattle.

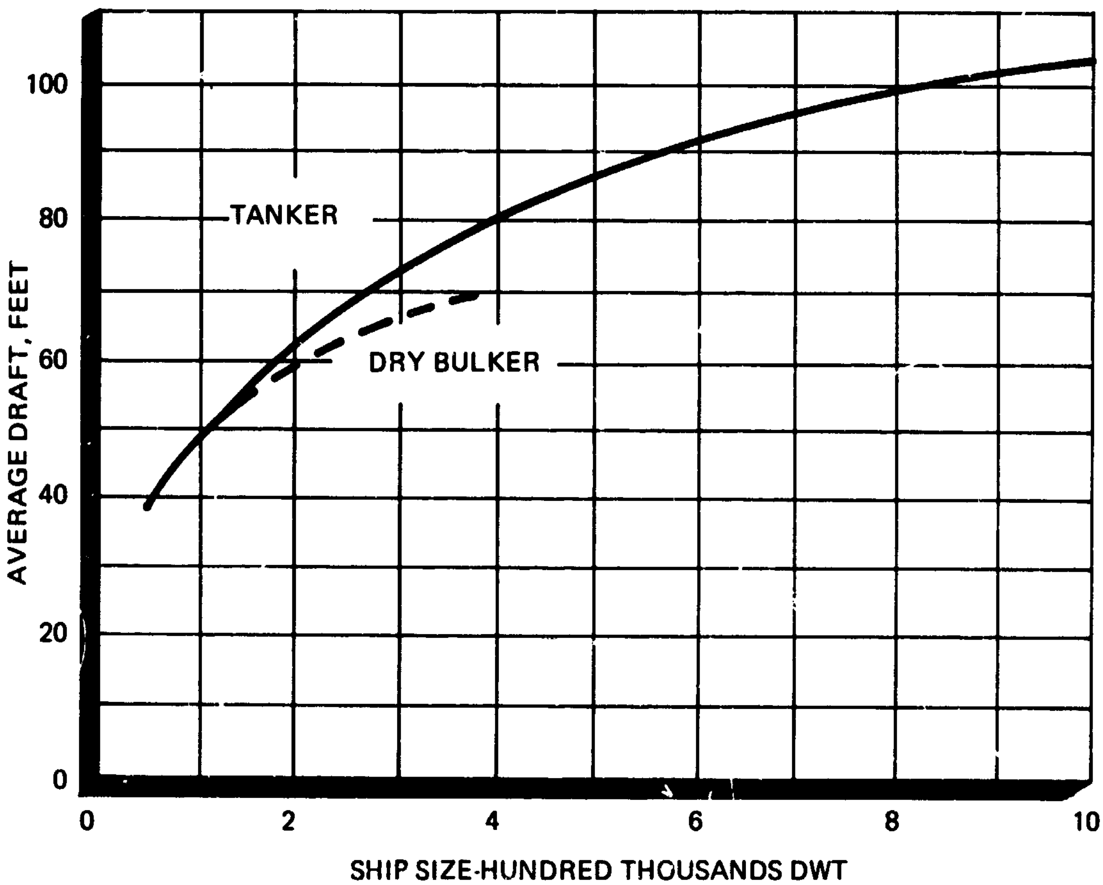
Required Landside Facilities

The tremendous volume of commodity deliveries associated with superships requires, in addition to deep harbors and channels, a great expansion in supporting facilities such as mooring facilities, piers, unloading facilities, tank farms, and storage areas. Inland distribution, or "feeder" transportation network may also require considerable modification or redevelopment to insure prompt dispatch and timely receipt of the huge commodity loads.

Problems of Harbor Deepening

Exploitation of the superships requires consideration of the sharply increased costs directly associated with the channel and harbor improvement, and indirect costs associated with such factors as environmental and ecological changes.

Possibly the most significant problem associated with major enlargement of harbors and channels is the cost of dislocations and major relocations of the extensive developments which have grown to the water's edge at most of the Nation's harbors. For example, at Oakland, California, substantial deepening of the harbor would result in very high cost for



AVERAGE RELATIONSHIP BETWEEN DEADWEIGHT SIZE AND SHIP DRAFT OF TANKERS AND DRY BULKERS

FIGURE A4-2

modification of Army and Navy waterfront facilities as well as the densely developed city waterfront area. Numerous other problem areas can be cited.

Many of the Nation's harbors have man-made channels, but most of them have been constructed by the removal of silt deposits. In a growing number of cases further deepening would encounter increasingly harder materials which are increasingly expensive to remove. Another changing condition is determined by the contour of the continental shelf. For example, deepening the offshore channel for Sabine Pass on the Gulf Coast only four feet would entail extending the length of the channel by 15 miles.

Disposal of the material excavated from the channels is becoming an increaing problem as available spoil areas become filled. The alternative of spoiling in deep water involves considerable added expense.

Another area of increasing concern is the effects of the harbor and channel construction and soil disposal on the environmental and ecological aspects of the biologically rich estuarine areas often involved in the channel and harbor developments.

Table A4-2 summarizes some of the problems associated with harbor deepening in the United States. The data shown in the table have been gathered from available sources without specialized or detailed studies, and, in many cases, are very preliminary in nature. No judgment of the feasibility of future harbor improvements is intended. "Problem depths," as identified in the table, are levels at which a given obstacle may begin to present serious problems. The difficulties associated with these obstacles can be expected to increase with depth.

U.S. and Canadian Harbor Development in the Near Future[1]

Although development of U.S. harbors to accommodate the larger ships that are now appearing is hindered by many problems, pressures to enlarge harbors and the channels leading to them or to build new harbors and channels are mounting. The following paragraphs outline plans for such development in the United States and Canada.

An iron ore loading dock was built at Sept Iles in the Gulf of St. Lawrence to accommodate 90,000 to 100,000 DWT ships by 1968. It is planned to deepen the facility to handle 150,000 DWT to 200,000 DWT ore ships ultimately.

Planning is underway for "Canport", a new harbor near St. Johns, New Brunswick, capable of handling ships up to 300,000 DWT. The venture would cost $40 to $50 million.

Two major U.S. oil companies are considering deep ports for large tankers at Machiasport, Maine. The size of vessels to be accommodated is expected to be 200,000 DWT or larger.

Plans are underway and construction has been announced for a new deepwater oil port on Long Island, in Casco Bay, near Portland, Maine. The announced cost including oil storage facilities and dredging to 85 feet is $140 million. The construction is planned for completion in 1971. The facility would receive Middle East crude oil, and Alaskan crude oil if the Northwest Passage is found navigable. The crude oil would be transshipped to refineries at other locations in smaller tankers. Some of the crude oil could be delivered to Montreal refineries through an existing pipeline.

[1] Conditions as of September 1969.

TABLE A4-2

POSSIBLE OBSTACLES TO HARBOR DEEPENING[1]

Harbors	Authorized Depth[2]	Major Relocations[3]	Dislocations[4]	Rock and/or Continental Shelf
		(Beginning depth of problem — in feet)		
ATLANTIC COAST				
NEW ENGLAND				
Boston Harbor	40	40	50	60
Bridgeport Harbor	35			60
Cape Cod Canal	32	45	40	40
Dorchester Bay and Neponset River	35			60
Fall River Harbor	30	45		60
Mystic River	35		45	40
New Bedford and Fairhaven Harbor	30	40		35
New Haven Harbor	35			40
New London Harbor	33			60
Portland Harbor	45	45		60
Portsmouth Harbor and Piscataqua River	35	50	45	35
Providence River and Harbor	40			55
Salem Harbor	32			60
Searsport Harbor	35			60
Weymouth-Fore and Town Rivers	35	45	50	40

[1] The data shown in the table have been gathered from available sources without specialized or detailed studies, and in many cases, are very preliminary in nature. No judgment of the feasibility of future harbor improvements is intended. "Problem depths," as identified in the table, are levels at which a given obstacle may begin to present serious problems. The difficulties associated with these obstacles can be expected to increase with depth.

[2] Maximum depth for outer harbor, unless otherwise noted. Lesser depths are often authorized for inner harbors.

[3] Major relocations include relocation or replacement of major bridges, highway and railway tunnels, utilities, or in-harbor structures such as breakwaters or jetties.

[4] Dislocations include relocation, replacement or loss of port facilities (piers, terminals, etc.) or industrial, commercial and residential structures, which are located adjacent to existing channels.

TABLE A4-2

POSSIBLE OBSTACLES TO HARBOR DEEPENING (Cont'd.)

Harbors	Authorized Depth	Major Relocations	Dislocations	Rock and/or Continental Shelf
		(Beginning depth of problem - in feet)		
ATLANTIC COAST				
NORTH ATLANTIC				
Baltimore Harbor	42	60		
Buttermilk Channel	40	45		
Channel to Newport News	45	55		
Delaware River, Philadelphia to the Sea	40			41
Delaware River, Philadelphia to Trenton	40	50		41
East River	40	50		40
Hudson River Channel	48	48		
Newark Bay, Hackensack and Passaic Rivers	35	60	[5]	35
New York and New Jersey Channels	35		45	38
New York Harbor	45	60		
Norfolk Harbor				
45-Ft Section	45	55		
40-Ft Section	40	45		
35-Ft Section	35	35		
Thimble Shoal Channel	45	55		
York River Entrance Channel	37[6]	60		
SOUTH ATLANTIC				
Brunswick Harbor	30			32
Canaveral Harbor	37	43	37	
Fernandina Harbor	32	34	34	
Jacksonville Harbor	42	48	42	44
Key West Harbor	30[7]	36	34	34
Miami Harbor	30	36	30	32
Morehead City Harbor	35	60	50	50
Palm Beach Harbor	35	41	35	37

[5] Improvement of Newark Bay, Hackensack and Passaic Rivers is governed by depths in New York and New Jersey Channels.

[6] Improved by U.S. Navy to depth of 39 feet in 1952. Currently has a controlling depth of 37 feet.

[7] Channel deepened to 34 feet by U.S. Navy.

TABLE A4-2

POSSIBLE OBSTACLES TO HARBOR DEEPENING (Cont'd.)

Harbors	Authorized Depth	Major Relocations	Dislocations	Rock and/or Continental Shelf
		(Beginning depth of problem - in feet)		
ATLANTIC COAST				
SOUTH ATLANTIC (Cont'd.)				
Port Everglades Harbor	40	46	40	42
Savannah Harbor	38	44		
Wilimington Harbor, North Carolina	38	60	50	38
GULF COAST				
Calcasieu River and Pass	40		40	
Charlotte Harbor	32	38	32	
Freeport Harbor	38	38		
Galveston Harbor	42			52
Gulfport Harbor	30		50	
Houston Ship Channel	40	45	50	
Mississippi River, Baton Rouge to Gulf of Mexico	40	40	40	
Mobile Harbor	40		45	
Panama City Harbor	34		45	
Pascagoula Harbor	38	50	45	
Port Aransas Corpus Christi Waterway	42	50		
Sabine-Neches Waterway	42	50	50	47
Tampa Harbor	36	42	36	38
Texas City Channel	40			52
PACIFIC COAST				
Columbia River Entrance	48	48		
Columbia and Lower Willamette Rivers	40	45	40	40
Coos Bay				
Entrance Channel	40	40		40
Inner Channel	30			30
Grays Harbor	30		45	30

TABLE A4-2

POSSIBLE OBSTACLES TO HARBOR DEEPENING (Cont'd)

Harbors	Authorized Depth	Major Relocations	Dislocations	Rock and/or Continental Shelf
		(Beginning depth of problem - in feet)		
PACIFIC COAST (Cont'd.)				
Humboldt Harbor and Bay (Inner Channel)	26		30	
Los Angeles-Long Beach				
Los Angeles	40	45	42	
Long Beach	35	50	35	
Oakland Harbor				
Outer Harbor	35	100	35	300
Inner Harbor	35	35	35	300
Puget Sound Harbors (Bellingham, Anacortes, Everett, Seattle, Tacoma, Olympia and Port Angeles)	Depths in Puget Sound range up to 900 feet. Improvements normally are associated with short service channels.			
Redwood City Harbor	30	100	35	150
Richmond Harbor				
West Richmond Chan.	45			200
Long Wharf	45		45	100
Southhampton Shoal	35			100
Inner Harbor	35		85	36
Santa Fe Channel	30		30	36
San Diego Harbor (Bay Channel)	35	50	40	
San Francisco Harbor				
Bar Channel	55			300
Islais Creek (Approach)	35	100		200
San Pablo Bay and Mare Island Straits				
Pinole Shoal Chan.	45			150
Oleum Pier	45		45	100
Mare Island Straits	30		50	100
Skipanon Channel	30		35	50
Yaquina Bay				
Bar Channel	40	40		40
Interior Channel	30			30

A consortium of oil companies organized as the Delaware Bay Transportation Company has under investigation an offshore unloading facility for tankers in lower Delaware Bay. A pipeline would deliver the oil to existing refineries. Dredging would be required to provide channels for 200,000 DWT tankers.

A plan for constructing two offshore submarine pipeline unloading facilities, one located seven miles east of Long Branch, New Jersey, and the other located east of Cape Henlopen, Delaware, has been proposed recently by First State Pipeline Company who would hope to build such facilities for accommodating tankers of upwards of 250,000 DWT.

Bethelem Steel announced in 1968 and 1969 that they would expand their works at Sparrows Point, Maryland, at a cost of $50 million. In connection with this expansion, channel deepening would be required from the present 42 feet to 50 feet to permit 100,000 DWT to 135,000 DWT ships to deliver ore to the Sparrows Point plant.

Bethelem Steel is also planning to build a shipbuilding dock at Sparrows Point which would accommodate ships up to 210,000 DWT. Completion is scheduled for 1972. Newport News Shipbuilding and Drydock Company is planning a facility of similar capacity.

A deepwater port is under consideration at the mouth of the Mississippi River where deep water is only two miles from the river outlet.

The Committee on Public Works, House of Representatives, requested by resolution adopted October 19, 1967 that the Board of Engineers for Rivers and Harbors review reports on San Francisco Bay and all tributary deep ports.

A deepwater port, Roberts Bank, near Vancouver, British Colombia, is under construction and being readied for a coal contract between Japan and Canada. Accommodations are being provided for 150,000 DWT vessels.

An offshore tanker loading facility has been constructed at Cook Inlet, Alaska, and presently handles tankers up to 30,000 DWT when ice is encountered and up to 60,000 DWT during ice-free conditions. The ultimate capacity will be 100,000 DWT vessels.

The U.S. harbor problem is of increasing concern both to Government and Industry. The American Association of Port Authorities (AAPA) has recently published a forecast in a report entitled, "Merchant Vessel Size in the United States Offshore Trades by the Year 2000," which highlights the need for planning to accommodate the larger sizes of vessels which will serve in this country's trade. The projections in this forecast provide a basis for translation into an assessment of long-range facilities requirements on a regional basis. The AAPA projections and estimates provide an excellent point of departure for requisite federal studies to guide future decisions on either federally-financed improvement projects or federal permits for the location of privately financed facilities in waters for which the U.S. has custodial responsibility.

Relationships of U.S. Harbors to a Sea-Level Canal

The present Panama Canal and its potential successor, the sea-level canal, constitute an integral part of the oceanborne transportation system serving the United States. As such, the sea-level canal should be capable of serving the ships which will also serve the U.S. ports. The current stage of study and development of U.S. ports as described in the foregoing can only indicate the trend in the broadest of terms. Only three U.S. ports can now handle 100,000 DWT vessels, and consideration is being given to serving 200,000 DWT crude oil carriers at several proposed deepwater facilities. The many constraints to increasing the

present depths of U.S. harbors are likely to limit the development of deep draft terminal facilities to a few strategically located regional ports and offshore loading and unloading facilities, but at least this minimum will be built. On the basis of both U.S. and foreign port development plans, few ships larger than 250,000 DWT are expected to be in service anywhere, and few in excess of 200,000 DWT will serve U.S. ports. Therefore, a 250,000 DWT vessel is indicated to be the largest that should be considered in planning a sea-level canal.

Appendix 5

STUDY OF SHIP DELAY COST AND RELATED CANAL LOCATION BENEFITS

Introduction

This Appendix addresses two interrelated considerations. The first pertains to the cost of delay of a ship and the second concerns the relative benefits of the several canal routes with respect to voyage mileage, time, and cost.

Delay Cost

The type of delay primarily considered was that encountered at the mouth of a canal due to congestion. In this situation, fuel is not being burned for propulsion. An analysis of present day costs was made versus deadweight tonnage with the results being plotted on Figure A5-1.

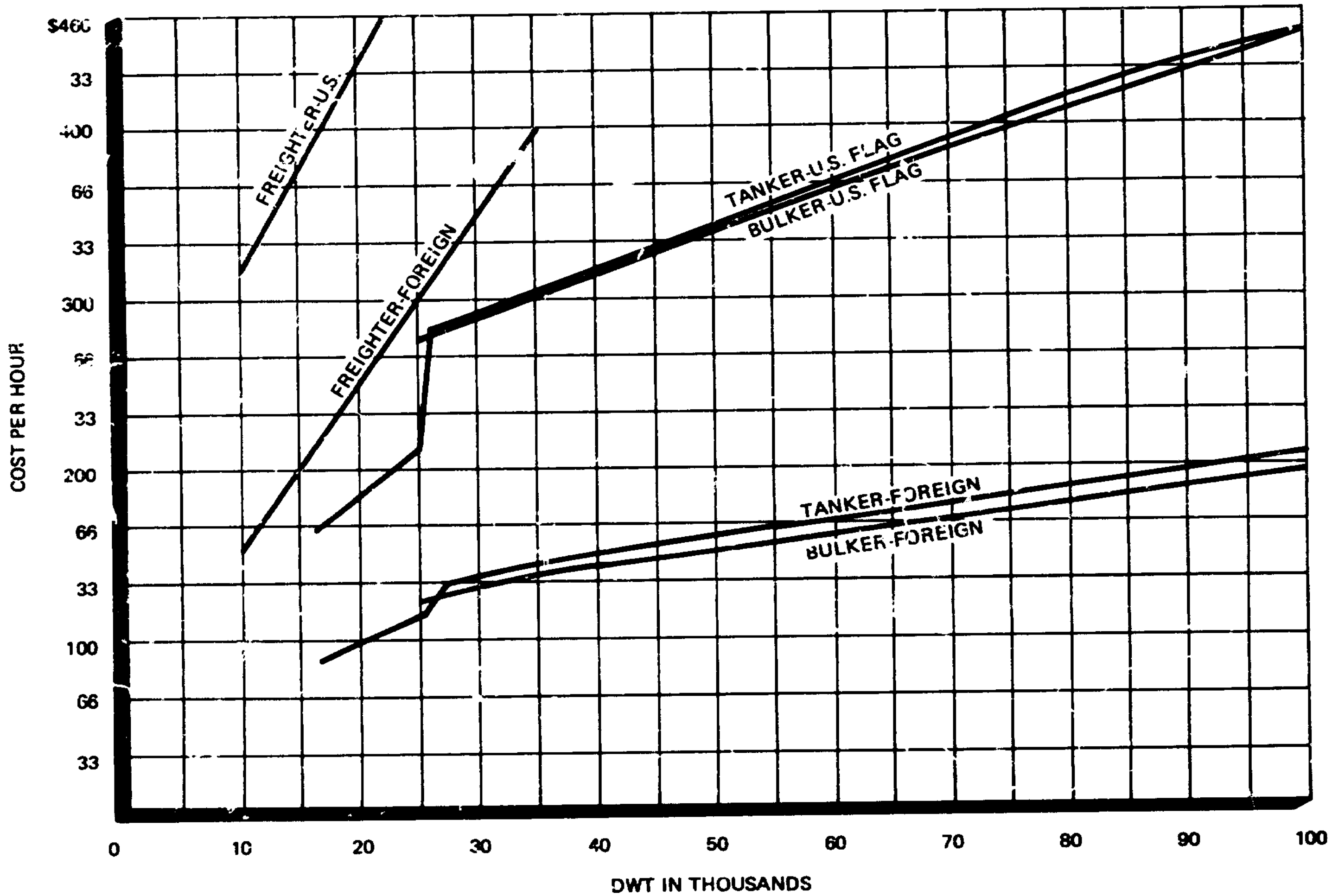
Hourly operating costs of vessels vary according to their size, age, type, state of repair, the flag under which they are operated and the skill of the owners, superintendents, officers and crew who operate them. The delay costs should be considered as a fixed charge irrespective of the trade in which a vessel is operated. Voyage expenses which vary by reason of employment, i.e., bunkers consumed at sea, port charges, cargo handling expenses, agency fees and commissions are not included; however, a cost per hour for bunkers consumed in port is included in the cost of the delay.

The calculation of the average delay cost for all vessel types is illustrated by Table A5-2. Average costs per deadweight hour from Figure A5-1 are weighted by Flag (U.S. vs. Foreign) and again for the percentage of transits by type from Table A5-1 to determine the average cost per deadweight hour for the "average" vessel transiting the canal in 1970. The delay cost for the "average" vessel of 14.1 thousand deadweight tons is calculated to be $158.60 per hour.

Canal Location Benefits

In order to compare the relative geographical benefits of Routes 8, 14, and 25 with respect to sea lane distances, accurate distances were determined from each Route terminus to major world ports served by the canal. These are shown on Figure A5-2.

To determine the present relative benefits in terms of ton miles saved by each route, a judgment sample consisting of more than 90 percent of the total commercial cargo moving through the Panama Canal in 1968 was analyzed. The results are tabulated in Table A5-3. A negative sign indicates a net saving and a positive sign indicates an additional number of miles over the existing Panama Canal route (or Route 14).



GENERAL CARGO, BULK CARRIER AND TANKER-COST VS. DWT
FY 1970 DOLLARS

FIGURE A5-1

TABLE A5-1

PROJECTED AVERAGE SHIP SIZE BY TYPE & FREQUENCY

		Table A1-8 26,800 Max. Transit Capacity 65,000 DWT			Table A1-11 0 Max. Transit Capacity 150,000 DWT			Table A1-13 0 Max. Transit Capacity 250,000 DWT		
		Tank	B.C.	Frt.	Tank	B.C.	Frt.	Tank.	B.C.	Frt.
1970	Ave. Dwt/Type	19.2	27.8	10.8	20.1	28.0	10.8	20.1	28.0	10.8
	Ave. Dwt/Transit		14.1			14.2			14.2	
	Pct. Transit/Type	12.8	13.3	73.8	12.4	13.3	74.3	12.4	13.3	74.3
1980	Ave. Dwt/Type	27.7	33.9	11.5	33.0	36.0	11.5	33.3	36.2	11.5
	Ave. Dwt/Transit		15.9			16.2			16.3	
	Pct. Transit/Type	10.0	12.3	77.8	8.6	11.8	79.6	8.5	11.8	79.7
1990	Ave. Dwt/Type	33.0	39.8	12.2	44.8	43.7	12.2	46.0	44.1	12.2
	Ave. Dwt/Transit		17.2			17.8			17.9	
	Pct. Transit/Type	9.1	11.3	79.6	6.9	10.7	82.4	6.8	10.6	82.6
2000	Ave. Dwt/Type	36.0	44.4	13.0	55.0	51.6	13.0	57.5	52.2	13.0
	Ave. Dwt/Transit		18.5			19.4			19.4	
	Pct. Transit/Type	9.0	10.9	80.1	6.1	9.8	84.0	5.9	9.8	84.3
2020	Ave. Dwt/Type	37.0	48.8	14.6	66.6	65.8	14.6	72.3	67.2	14.6
	Ave. Dwt/Transit		20.5			22.1			22.3	
	Pct. Transit/Type	9.7	11.0	79.3	5.8	8.8	85.4	5.4	8.7	86 0
2040	Ave. Dwt/Type	37.0	52.0	16.5	74.6	81.0	16.5	87.2	85.0	16.5
	Ave. Dwt/Transit		22.8			25.2			25.5	
	Pct. Transit/Type	10.7	11.5	77.8	5.9	8.1	86.0	5.1	7.9	87.0

NOTE: Average ship size in (000) tons Dwt.

Source: Appendix 1 Computation of Projected Revenue 65,000 Dwt maximum ship size; 150,000 Dwt maximum ship size; and 250,000 Dwt maximum ship size.

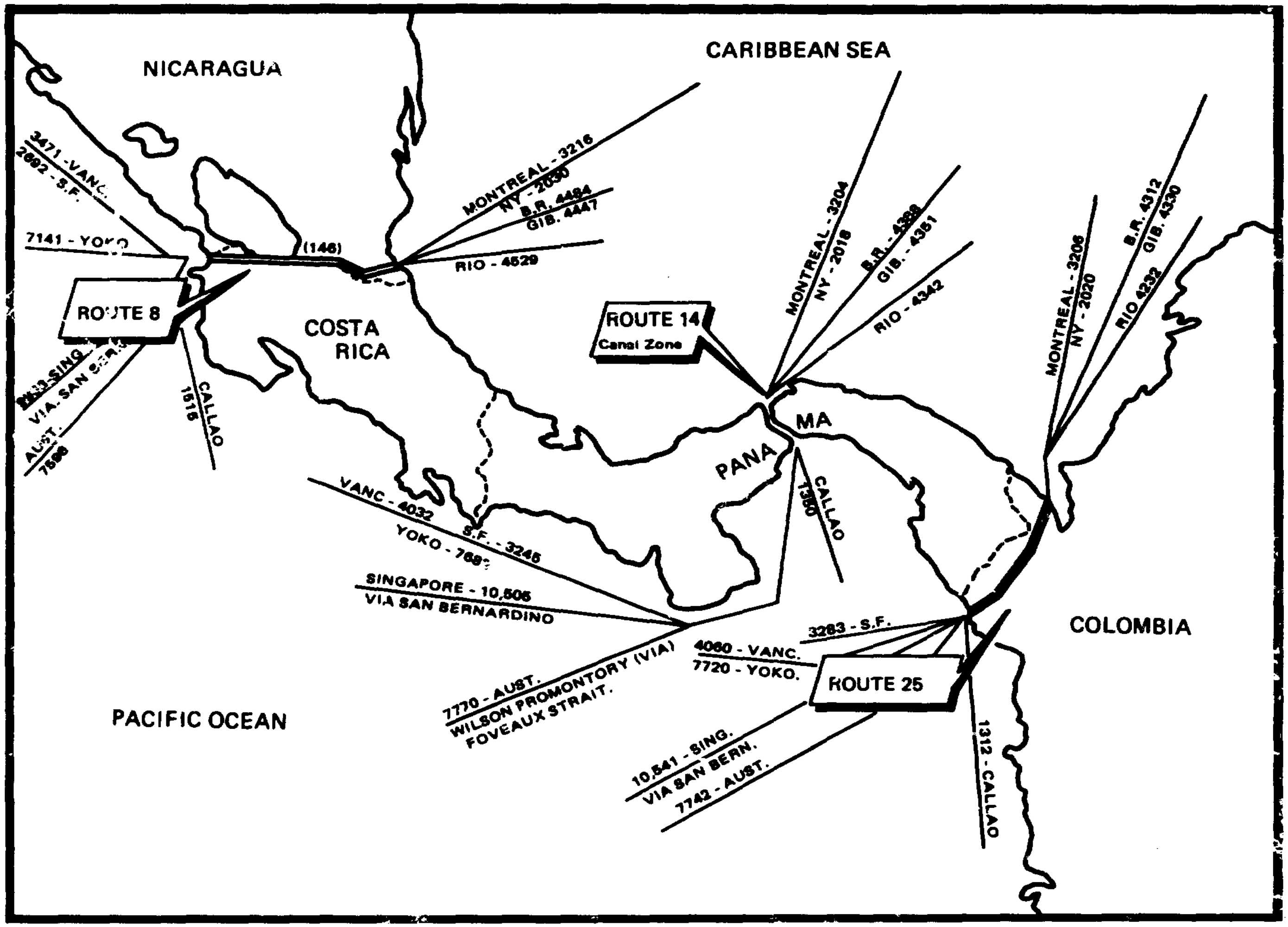
TABLE A5-2

CALCULATION OF AVERAGE DELAY COST FOR ALL VESSEL TYPES

1970 – 65,000 DWT Max. Size

		Av. Cost Per Hr.		Pct. Flag Transits F.Y. 1968		Av. Cost By Type		Pct. Transits By Type From Table A5-1		Cost of Av. Vessel Per Hr.
Bulkers	US	282	x	12.5	=	35.25				
	FOR.	124	x	87.5	=	108.50				
						143.75	x	13.3	=	$ 19.12
Tankers	US	177	x	12.5	=	22.13				
	FOR.	95	x	87.5	=	83.13				
						105.26	x	12.8	=	$ 13.47
Freighters	US	316	x	12.5	=	39.50				
	FOR.	150	x	87.5	=	131.25				
						170.75	x	73.8	=	$126.01
Cost per hour for average vessel F.Y. 1970 (Average vessels DWT 14.1 thousand tons – see Table A5-1									=	$158.60

Note: U.S. flag transits in F.Y. 1968 were 12.5% of total traffic as reported by Panama Canal Company, Canal Zone Government, Annual Report



MAP OF WORLD PORT DISTANCES TO ALTERNATE ROUTES 8, 14, 25

FIGURE A5-2

TABLE A5-3

GEOGRAPHIC COMPARATIVE ADVANTAGE OF ROUTES 8 AND 25
VIS-A-VIS PANAMA CITY, PANAMA

Trade Route		Distances (Nautical Miles) Via Route 8	Panama	Route 25	Trade A-P*	Totals P-A*	(000LT) Total
East Coast USA (N.Y.)	–West Coast USA	(-395)	5263	+127	2994	1719	4713
	–Japan	(-383)	9700	+127	24299	4790	29089
	–Singapore	(-367)	12523	+125	4433	2487	6920
	–Australia	(- 14)	9788	+ 61	1418	986	2404
	–West Coast S.A.	+323	3368	+ 51	1849	4828	6677
	–West Coast Canada	(-403)	6050	+117	230	1750	1980
Europe (Bishops Rock)	–West Coast USA	(-311)	7633	+ 49	1071	2424	3495
	–Japan	(-299)	12070	+ 49	3306	568	3874
	–Singapore	(-283)	14893	+ 47	133	0	133
	–Australia	+ 70	12158	(- 17)	843	1836	2679
	–West Coast S.A.	+407	5738	(- 27)	1177	4563	5740
	–West Coast Canada	(-319)	8420	+ 39	266	3761	4027
East Coast S.A. (Rio de Janeiro)	–West Coast USA	(-220)	7587	+ 15	2180	161	2341
	–Japan	(-208)	12024	+ 15	1352	279	1631
	–Singapore	(-192)	14847	+ 23	84	45	129
	–Australia	+161	12112	(- 51)	40	11	51
	–West Coast S.A.	+498	5692	(- 61)	3557	93	3650
	–West Coast Canada	(-228	8374	+ 5	136	131	267
East Coast Canada (Montreal)	–West Coast USA	(-395)	6449	+127	24	45	69
	–Japan	(-383)	10886	+127	527	128	655
	–Singapore	(-367)	13709	+125	143	80	223
	–Australia	(- 14)	10974	+ 61	243	234	477
	–West Coast S.A.	+323	4554	+ 51	82	17	99
	–West Coast Canada	(-403)	7236	+117	0	93	93

TABLE A5-3

GEOGRAPHIC COMPARATIVE ADVANTAGE OF ROUTES 8 AND 25 VIS-A-VIS PANAMA CITY, PANAMA (Cont'd.)

		Distances (Nautical Miles) Via			Trade	Totals	(000LT)
Trade Route		Route 8	Panama	Route 25	A-P*	P-A*	Total
West Indies	—West Coast USA	(-533)	3245	+ 38	2502	465	2967
Carib Sea	—Japan	(-541)	7682	+ 38	1994	151	2145
Entrance to	—Singapore	(-525)	10505	+ 36	390	319	709
Canal	—Australia	(-182)	7770	(- 28)	3	458	461
	—West Coast S.A.	+165	1350	(- 38)	677	241	918
	—West Coast CAnada	(-561)	4032	+ 28)	328	150	478
					56,281	32,813	89,094

Total Commercial Trade F.Y. 1968: 96,550

NOTE: A-P Atlantic Pacific

Source: Panama Canal Company Annual Report Trade Totals

Excluding the consideration of time required for delay in waiting for convoy and in the actual passage through the canal, Table A5-3 shows that Route 8 presently could effect a yearly savings of 18 billion ton-miles over Route 14 and that Route 14 could effect a 6 billion ton-mile savings over Route 25.

Translating the foregoing in the instance of 18 billion ton-mile savings into the average effect on an average ship of 14,100 DWT for a year's time, the yearly savings per ship would be about 8.2 hours steaming time at the world average speed of 14 knots. This would be worth about $1600.

Factors such as waiting time for convoy and greater ship speeds could render the foregoing relative benefits of small significance.

THE ATLANTIC-PACIFIC INTEROCEANIC CANAL STUDY COMMISSION

Annex V
Study of Engineering Feasibility

ANNEX V

STUDY OF

ENGINEERING FEASIBILITY

– – –

INTEROCEANIC CANAL STUDIES – 1970

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PART III. EVALUATION OF ROUTES

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*Available from National Technical Information Service, Springfield, Va. 22151.

REPORT OF THE ENGINEERING AGENT TO THE ATLANTIC-PACIFIC INTEROCEANIC CANAL STUDY COMMISSION

STUDY OF ENGINEERING FEASIBILITY, INTEROCEANIC CANAL STUDIES - 1970

DIGEST

The Study of Engineering Feasibility was made pursuant to a request by the Atlantic-Pacific Interoceanic Canal Study Commission that the Chief of Engineers determine the engineering feasibility of constructing a sea-level canal between the Atlantic and Pacific Oceans and develop preliminary plans and cost estimates for such a canal. (See pp. V-1 to V-7.)

A general review was made of basic considerations underlying selection of routes for an interoceanic canal, including criteria which determine its configuration, means available for its construction, cost factors involved, and its ecological implications. Six sea-level canal routes and two lock canal routes studied previously were considered worthy of further investigation. During the course of the investigation three sea-level routes were found sufficiently promising to warrant detailed study and comparison.

The study's principal findings may be summarized as follows.

- Several alternative methods of conventional excavation might be employed. (See pp. V-53 to V-63.) Nuclear excavation technology is potentially advantageous, but has not yet reached a state of development which would permit its application if this project were to be undertaken. (See pp. V-65 to V-81.)
- There are no insolvable engineering problems involved in the conventional construction and operation of a sea-level canal across the American Isthmus. (See pp V-83 to V-90.)
- Despite limited experience in navigating large ships through restricted waters, conservative channel design criteria can be specified. (See pp V-91 to V-112.)
- The Deep Draft Lock Canal Plan for the Panama Canal is clearly preferable to other lock canal options in Panama and Nicaragua. (See pp V-125 to V-143.)
- The best sea-level canal alternatives are Routes 10 and 14S. The preferred alinement is along Route 10, crossing Panama 10 miles southwest of the existing canal. Route 14S, an alinement along the Panama Canal, is also acceptable. Route 10 is preferred because its construction would not interfere with, or endanger, Panama Canal operations; it would permit continued use of the Panama Canal as a supplementary facility, and would be easier to expand than Route 14S. Route 10 is also preferable to the Deep Draft Lock Canal Plan. Construction of a sea-level canal along Route 10 would require 14 years at a cost of about $2.9 billion. (See pp V-223 to V-262.)
- If nuclear excavation could be used, Route 25 in Colombia would be the preferred alternative. (See pp V-263 to V-277.)

- The canal's construction should be directed by an autonomous agency authorized to draw upon the resources of existing Federal construction agencies. (See pp V-289 to V-292.)
- The canal should be operated by an agency created specifically for that purpose, with authorities and responsibilities similar to those of the Panama Canal Company. (See pp V-292 to V-293.)
- To ensure that the new canal is available when the Panama Canal reaches its capacity, detailed design should begin in 1976 and should be preceded by investigations of those engineering aspects required for determination of an optimum design. Fields requiring further investigation include subsurface geology, ecology, nuclear excavation, slope stability, and navigation in restricted waterways. (See pp V-297 to V-302.)

PART I – INTRODUCTION

CHAPTER 1

THE STUDY EFFORT

The *Study of Engineering Feasibility* is one of five annexes to *Interoceanic Canal Studies – 1970*, the report of the Atlantic-Pacific Interoceanic Canal Study Commission, 1 December 1970. This annex was prepared in support of the Commission's efforts, under the guidance of an interdepartmental and interagency group chaired by the Deputy Director of Civil Works, Office of the Chief of Engineers, who also served as Engineering Agent for the Commission. The other annexes, prepared by other study groups, cover related aspects of foreign policy, national defense, finance, and shipping requirements.

Purpose: Public Law 88-609, 22 September 1964, which established the Atlantic-Pacific Interoceanic Canal Study Commission, called upon the Commission:

> to make a full and complete investigation and study, including necessary onsite surveys . . . . . . for the purpose of determining the feasibility of, and the most suitable site for, the construction of a sea-level canal connecting the Atlantic and Pacific Oceans; the best means of constructing such a canal, whether by conventional or nuclear excavation, and the estimated cost thereof.[1] *

To accomplish these purposes, the Commission, on 17 September 1965, approved the *Plan for Study of Engineering Feasibility*[2], which listed as its objectives:

> (1) A determination of engineering feasibility of constructing a sea-level canal connecting the Atlantic and Pacific Oceans, both nuclear and non-nuclear.
> (2) The development of preliminary plans and cost estimates of construction of a sea-level canal by nuclear methods.
> (3) Preliminary plans and cost estimates of conversion of the present canal to sea level.
> (4) Economic analysis of benefits and costs of alternative canals.

*Refers to references listed on page V-307.

The economic analysis was subsequently reassigned. It appears in Annex III, *Study of Canal Finance*, and Annex IV, *Study of Interoceanic and Intercoastal Shipping*.

Methodology: The methodology applied to the *Study of Engineering Feasibility* is reflected in the general framework of this report. In order, the principal steps in the study were:

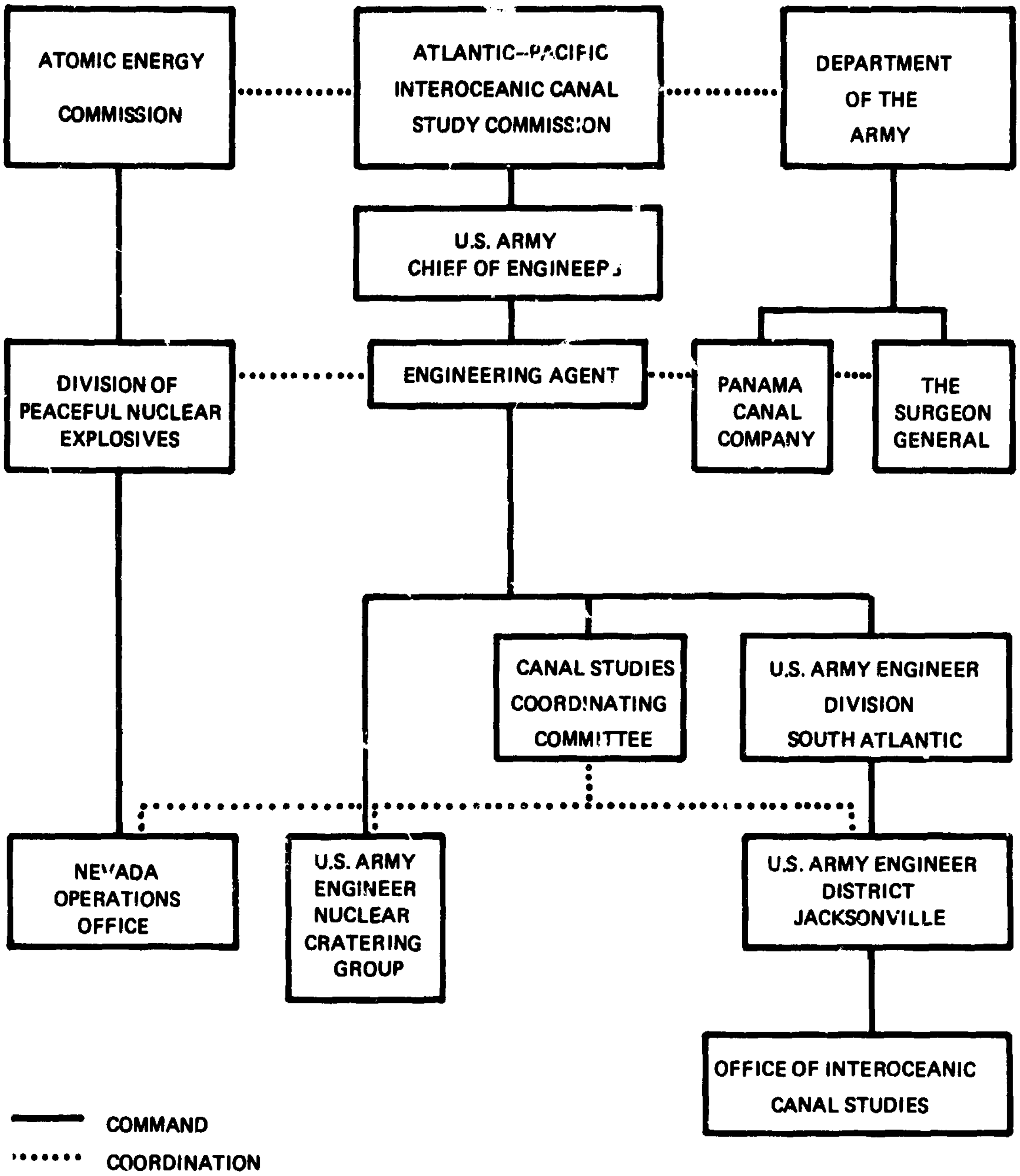
- Review data available om previous investigations.
- Select the routes to be studied.
- Collect necessary data in the field.
- Evaluate data and develop general design criteria.
- Apply these criteria to the routes under study, arriving at conceptual designs and associated construction cost estimates.
- Evaluate these routes to select the most promising as alternatives to be considered in greater detail.
- Analyze and compare these alternatives to determine the best engineering solution.

Organization of the study effort: By resolution of 16 July 1965, the Commission requested that the Secretary of the Army designate the Chief of Engineers to be its agent for conducting engineering feasibility studies in direct coordination with the Atomic Energy Commission, the Panama Canal Company, and the Surgeon General, U.S. Army. This appointment was formalized on 24 July 1965, at which time the Secretary of the Army authorized the Chief of Engineers to redelegate his responsibilities and authorities. These were passed on 11 October 1965 to the Deputy Director of Civil Works.

With two exceptions, the Engineering Agent made the District Engineer, Jacksonville, responsible for data collection in the field and for the conduct of engineering studies. Excepted activities were those related to nuclear operations and safety, responsibility for which was assigned to the Atomic Energy Commission; and nuclear excavation design, for which the U.S. Army Engineer Nuclear Cratering Group, working in coordination with the Atomic Energy Commission, was made responsible.[3] On 22 July 1965, the Interoceanic Canal Studies Field Office, an agency of the Jacksonville District, was established in the Canal Zone under a Field Director to perform all functions related to onsite data collection.[3] Political agreements were negotiated with Panama and Colombia, creating joint commissions in both countries to facilitate the Field Director's work. He represented the United States on those commissions until his office was inactivated on 31 July 1969.[4]

The Canal Studies Coordinating Committee was created to assist the interchange of information among the various agencies involved in field investigations; it also participated in evaluating data and preparing reports. The District Engineer, Jacksonville, served as its chairman. Figure 1 shows the organization which conducted the study. Table 1 lists the major agencies which cooperated to produce its component parts.

Supporting these organizations were numerous universities, laboratories, engineering firms and institutions–both in the United States and overseas–performing tasks and providing information. Among those providing such support were the Hydrodynamics Laboratory of the Massachusetts Institute of Technology, the Institute of Ecology of the University of Georgia, the National Geographic Society, the Institute of Marine Sciences of the University of Miami, the National Academy of Sciences, the Smithsonian Institution,



ORGANIZATION OF THE
STUDY EFFORT

FIGURE 1-1

TABLE 1-1

DISTRIBUTION OF THE STUDY EFFORT

Agency	Responsibility
U.S. Army Corps of Engineers	
Office, Chief of Engineers	Management and technical review: preparation of Annex V
South Atlantic Division	Engineering supervision and laboratory support
Jacksonville District	Engineering analysis and estimates; preparation of Appendixes 1, 2, 4, 5, 6, 7, 8, 9, 10, 14, 15, and 17.
Interoceanic Canal Study Field Office	Data collection
Nuclear Cratering Group	Nuclear construction engineering; preparation of Appendixes 11, 12, and 13.
Canal Study Coordinating Committee	Coordination of study effort
Atomic Energy Commission	
Division of Peaceful Nuclear Explosives	Supervision and review of nuclear studies
Nevada Operations Office	Nuclear operations and safety; preparation of Appendixes 3 and 16.
Principal Contractors:	
Lawrence Radiation Laboratory	Nuclear cratering technology
Environmental Science Services Administration	Conduct of meteorological studies
Sandia Corporation	Acoustic wave characteristics
Battelle Memorial Institute	Environmental field studies and analyses
Environmental Research Corporation	Ground motion studies
John A. Blume & Associates	Structural response studies
Panama Canal Company	General support of the field effort and application of Panama Canal experience
The Surgeon General, U.S. Army	Medico-ecology studies and medical support of the field effort

the Puerto Rico Nuclear Center, the Stevens Institute of Technology, the U.S. Naval Ship Research and Development Center, the University of Florida, the University of Michigan, the U.S. Coast and Geodetic Survey, Oak Ridge National Laboratory, the Ecuadorian Institute of Anthropology and Geography, and the Waterways Experiment Station of the Corps of Engineers.

Throughout the conduct of this study, the best available professional opinions were sought and applied. A distinguished board of Technical Associates for Geology, Slope Stability, and Foundations advised and assisted the Commissioners and the Engineering Agent in their work. In particular, the Technical Associates were concerned with the stability of materials through which a canal might be excavated. Members of this board were:

Dr. Arthur Casagrande	Professor of Soil Mechanics, Harvard University
Dr. Frank Nickell	Consulting Geologist
Mr. Roger Rhoades	Consulting Geologist
Dr. Philip C. Rutledge	Mueser, Rutledge, Wentworth and Johnston, Consulting Engineers
Mr. Thomas F. Thompson	Consulting Geologist

A group of outstanding engineers advised the Engineering Agent on conventional construction systems which might be employed in building a sea-level canal. Members of the Board of Consultants for Conventional Earthwork Methods were:

Mr. L. Garland Everist	President, Western Contracting Corporation
Mr. Grant P. Gordon	Vice President, Guy F. Atkinson Company
Mr. J. Donovan Jacobs	President, Jacobs Associates
Mr. Lyman D. Wilbur	Vice President, Morrison-Knudsen Company, Inc.

The size of the force working full-time on this study was:

	End of fiscal year:				
	1966	1967	1968	1969	1970
Office personnel	59	90	73	87	43
Field personnel	404	744	261	184	0
TOTAL	463	834	334	271	43

Investigative effort: In some fields accumulation of information to support the *Study of Engineering Feasibility* was a relatively easy task; available records could be reviewed. In

others there were no records; data had to be collected and collated. In a few cases, existing technology was not adequate to permit analysis of information accumulated; new understandings of natural phenomena had to be reached.

This annex summarizes, integrates, and records the conclusions drawn from the many separate investigations that together constitute the *Study of Engineering Feasibility*. Detailed reports on the subjects covered in this study are presented in the appendixes.

Criteria were developed to specify the characteristics of a useful sea-level canal. Applying these criteria, alinements and designs were selected for each alternative route, and their construction costs were estimated. Out of this process came an understanding of the relationship between the configuration, construction cost, and transiting capacity of each route.

The collection and analysis of these data involved a considerable investment. The Commission's expenditures, by general category, were:

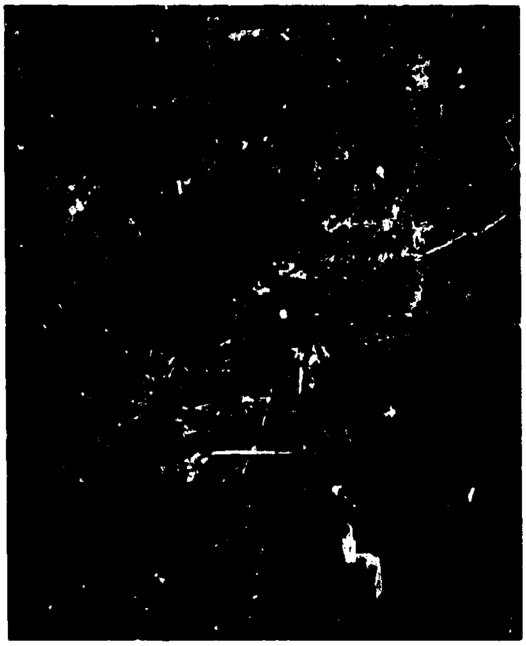
Field Data Collection (31.2%)		
Geology, hydrology, topography	$5,300,000	
Meteorology	2,700,000	
Bioenvironmental data	2,100,000	
Acoustic waves and seismic effects	300,000	
Medico-ecology	300,000	
Field construction and support	2,400,000	
Management	1,600,000	
SUBTOTAL		$14,700,000
Data Evaluation (25.0%)		
Nuclear excavation	$ 500,000	
Nuclear operations	2,800,000	
Conventional construction	2,700,000	
SUBTOTAL		$ 6,000,000
Commission and Engineering Agent (6.3%)		$ 1,500,000
Unexpended and turned back to U.S. Treasury (7.5%)		$ 1,800,000
TOTAL AUTHORIZED PROGRAM		$24,000,000

In addition to the funds which were appropriated for the Commission's use, expenditures were made by the Atomic Energy Commission to develop nuclear excavation technology for this study.

Besides advancing the theories underlying the design, construction, and operation of large canal facilities, investigations made in conjunction with this study produced significant

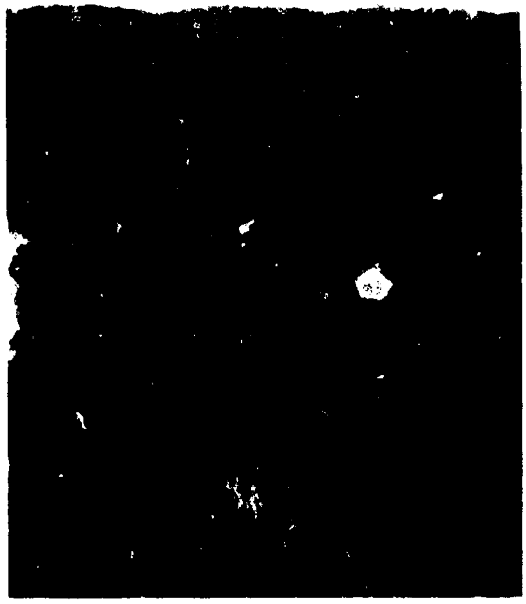
improvements in technology which are expected to have broad applications. Despite this progress, additional data and investigations should be undertaken before an interoceanic sea-level canal could be designed and constructed. Regardless of which route is chosen ultimately, more detailed geological explorations would be necessary. Understanding of engineering properties of certain weak rocks in deep cuts must be enlarged. Knowledge of the relationship among ship size, safe ship speed, and channel size must be expanded. The nature of consequent environmental changes must be determined. Nuclear excavation technology should be advanced and tested to the prototype level.

As a part of the PLOWSHARE Program, the Atomic Energy Commission included a series of nuclear cratering experiments designed to support this study. Not all of those experiments have been conducted; consequently, some objectives of this study have not been attained. Although enough is known of nuclear excavation theory to permit preliminary design and cost estimates for those alternatives involving nuclear excavation, the feasibility of nuclear excavation of an interoceanic sea-level canal has not yet been demonstrated. Designs and cost estimates of the conventionally-excavated alternatives described herein are based on established, proven practice; those involving nuclear excavation are not. Thus, while the present state of our knowledge permits comparison among and between nuclear alternatives, there is no valid basis for comparing the conventionally-excavated routes examined in this study with those to be excavated by nuclear means.



Aerial view of the centerline road established on Route 17. Road was impassable to all but tracked vehicles during the rainy season (8 months of the year).

Water transport was the main method of travel for the survey parties. Streams such as this had to be cleared before parties could travel further.



Work camps such as this were established along the routes. Camps were supplied by water or by helicopter.

Survey lines were cleared by native labor.

The areas investigated were mostly unexplored jungle. Survey parties were forced to travel mostly by water using native dugouts and outboard motors.

PART II – BASIC CONSIDERATIONS

In this part are discussed the basic considerations that governed the selection of routes for study. Also presented are the general characteristics of the regions in which these routes are located Criteria are developed for designing a canal capable of meeting projected requirements. Methods of excavation are described and costs–both quantified and unquantified–are defined.

CHAPTER 2

PREVIOUS STUDIES

Early efforts: The construction of an interoceanic sea-level canal through the American Isthmus was considered seriously as early as 1516 when Charles I of Spain* ordered a search for a strait across the American Isthmus. In the more than 4½ centuries since that time, numerous investigations have been made to determine possible locations and designs for a canal. The United States has played an active role in this effort since the mid-nineteenth century. Throughout the 1870's expeditions were sent out by the War and Navy Departments to explore the American Isthmus from Mexico to Colombia. In 1872 President Grant appointed the first United States Interoceanic Canal Commission to evaluate the Navy's surveys then in progress. In 1876, having assessed the available data, this three-man commission recommended construction of a lock canal across Nicaragua.[5]

The first significant attempt to bring an isthmian sea-level canal into being was made by a French company, *la Compagnie Universelle du Canal Interoceanique de Panama*, organized in 1879 by the builder of the Suez Canal, Ferdinand de Lesseps. Under his leadership, efforts were made to build a sea-level canal across the Isthmus of Panama. When it became apparent that this task was beyond its capabilities, the company turned to the construction of a lock canal, but again was unsuccessful and eventually went bankrupt. A second French company, *la Compagnie Nouvelle du Canal de Panama*, formed out of the assets of the de Lesseps organization, attempted to carry the work forward, but made little progress. Finally, in 1898, the company made overtures towards selling its assets to the United States.[5]

By the turn of the century, the United States had taken the lead in bringing this project to fruition. The Isthmian Canal Commission of 1899-1901 was appointed by President

*Later Charles V of the Holy Roman Empire

McKinley to direct all route investigations with a view toward construction of a canal by the United States. After sending exploratory expeditions to Nicaragua, Panama, and the Darien in 1899, this commission found the Nicaraguan and Panamanian routes to be about equally advantageous from an engineering viewpoint.[6] However, anticipating serious difficulties in acquiring the French assets and in obtaining access and operating rights in Panama, the Commission recommended the Nicaraguan route. When the French company reduced its demands to coincide with the Commission's appraisal of its assets, the Commission reversed its previous recommendation and informed Congress that, under these changed circumstances, it favored the Panamanian route.[5]

In 1902 Congress authorized the President to acquire rights to construct and operate a canal across either Panama or Nicaragua, and, having acquired such rights, to proceed with construction. In 1904 President Roosevelt appointed the first of three Isthmian Canal Commissions to plan and supervise the canal's construction in Panama.

An International Board of Consulting Engineers, appointed in 1905 to consider alternatives formulated by the first Commission, recommended a sea-level canal. Although the Senate Committee on Interoceanic Canals supported the views of the Board, in 1906 Congress enacted legislation adopting the President's position in favor of a high-level lock canal, hoping thereby to save both time and money. The present lock canal in Panama owes its existence to that decision.[5]

The 1929 Surveys: The Panama Canal was opened to traffic on 15 August 1914. Several years later those responsible for its operation grew concerned that demands for transit eventually might exceed its capacity. Thus, in 1929, Congress directed that surveys be made in Panama and Nicaragua[7] to determine the practicability of providing additional locks to the Panama Canal or of constructing a canal elsewhere.* The U.S. Army Interoceanic Canal Board of 1929-1931 was created by the President. The Board's report, submitted in 1931,[8] considered three long-term alternatives:

- Add a third set of locks to the Panama Canal;
- Convert the Panama Canal to a sea-level canal; or
- Construct a new lock canal in Nicaragua.

Anticipating increases in the capacity of the Panama Canal made possible by construction of Madden Dam,† the report concluded that:

> The present traffic seeking transit through the Isthmus and the prospective increase in such traffic in the next few years do not require that any steps be taken now to provide further capacity at Panama.

The Third Locks Plan: In 1936 a joint resolution of Congress[9] directed the Governor of The Panama Canal to investigate means of increasing capacity of the "Panama Canal for future needs of interoceanic shipping and for other purposes." The Governor's report[10]

*Lieutenant Colonel Daniel I. Sultan was in charge of a survey of lock canal routes conducted in Nicaragua by a provisional U.S. Army Engineer Battalion.

†The construction of Madden Dam in Panama had been authorized by Public Law 181, 70th Congress; however, at the time that the Board made its report, it was not yet in operation.

recommended a third lane of locks* and in August 1939, Congress authorized its construction. This measure was taken to improve the defensive posture of the Panama Canal and to increase its capacity. Excavation for the third locks at Gatun and Miraflores and design of structures and appurtenances were almost complete when the project was suspended in 1942 because of higher priority demands imposed by World War II. This work was not resumed when the war ended.

The 1947 report: In December 1945,[11] Congress again directed the Governor of The Panama Canal to make new investigations to determine the best means for increasing the canal's capacity and for improving its security, and to consider other possible routes.† This comprehensive effort, reported in *Isthmian Canal Studies-1947*,[12] identified 30 possible routes in five geographical areas ranging from the Isthmus of Tehuantepec, in Mexico, to northwestern Colombia. It went on to select the best route in each area for further consideration; and to compare these routes with one another.

In his report, the Governor concluded that a sea-level canal was both desirable and feasible, and that the best and most economical means for its development lay in converting the Panama Canal (called Route 15) to sea level. This conversion would be made by deepening and straightening the existing canal along a new alinement called Route 14.

Another investigation, conducted concurrently with the 1947 studies, sought to determine the effects of nuclear attacks upon lock and sea-level canals. Since principles of nuclear excavation were not clearly defined at that time, the possibility of using nuclear energy to excavate a new canal was not considered.

The Board of Consultants' report: Ten years later (1957) the House Committee on Merchant Marine and Fisheries appointed a Board of Consultants on Isthmian Canal Studies to investigate both short- and long-range plans for improving the Panama Canal. In 1958 the Board submitted its short-range program to increase the existing canal's capacity;[13] and, in 1960, it made additional recommendations providing for a long-range program of improvements.[13] Although stating that "no sea-level canal project in the Canal Zone should be undertaken in the near future," the consultants called for further studies and developmental efforts, particularly in the field of nuclear excavation, and recommended a review of the entire situation by 1970.

The 1960 report: In 1957 the Board of Directors of the Panama Canal Company appointed the *Ad Hoc* Committee for Isthmian Canal Plans to revise the 1947 report, taking full advantage of developments in construction techniques, and to adjust previous cost estimates to 1960 price levels. The Atomic Energy Commission participated in this study, identifying routes that might be suitable for nuclear excavation which, by then, had begun to emerge as a new technology. The Committee's recommendations did not address the

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*Considered during the original design of the Panama Canal, this plan was proposed formally by Colonel Harry Burgess, Governor of The Panama Canal from 1928 to 1932. It was first presented in the report of the U.S. Army Interoceanic Canal Board of 1929-1931. As revised in 1940, it called for locks 140 feet wide, 1,200 feet long and 45 feet deep, separated from and adjacent to each of the existing locks. Estimated cost of the project was $277 million.[10]

†On May 6, 1946 the Special Engineering Division, Panama Canal Company, was made responsible for the studies and Colonel James H. Stratton was designated Supervising Engineer.

construction of lock canals because, in its opinion, their operating costs would eventually escalate beyond available revenues.[14] Among the more significant recommendations developed by this study were those calling for:

- Completion, as an interim measure, of the Board of Directors' canal improvement program, calling for expenditures of $90 million through 1968 to increase the capacity of the lock canal;
- Initiation by the Company of planning for the construction of a sea-level canal outside the Canal Zone by nuclear methods;
- Improvement by the Atomic Energy Commission of nuclear explosives; and,
- Planning by the Company for construction of a sea-level canal in the Canal Zone by conventional methods if definite plans for constructing a sea-level canal by nuclear methods were not developed by the early 1970's.

The 1964 report: The report entitled *Isthmian Canal Studies, 1964,* was prepared by the President of the Panama Canal Company, pursuant to authorization in 1963 by the Company's Board of Directors. The Corps of Engineers, the Atomic Energy Commission and private consultants participated in its preparation.[15] The report summarized studies of canal capacity, canal traffic projections, and ways of improving the lock canal facilities to meet projected requirements of ocean commerce. The report contained a detailed analysis of a Third Locks Plan,* a Terminal Lakes Plan† and a sea-level canal in the Canal Zone.‡ The report also examined the present canal's transiting capacity, and concluded that a maximum of 71 ships (65 lockages) per day (about 26,000 per year) could be accommodated, assuming no maintenance shutdowns, and further assuming that either lockage water could be reused or sea water could be pumped into Gatun and Miraflores Lakes to augment the lockage water supply. The report also evaluated the technical feasibility of employing nuclear explosives to construct sea-level canals in eastern Panama and northwestern Colombia.

These and other significant studies and investigations are summarized in Table 2-1.

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*Under this version of the Third Locks Plan, the proposed locks would be 140 feet wide, 1,200 feet long and 50 feet deep, located adjacent to the existing locks.

†This plan had been proposed in 1943 by Capt. Miles P. DuVal, USN, then Captain of the Port at Balboa, Canal Zone, as a modification of the Third Locks Plan. It called for consolidating the Pacific Locks at Miraflores and raising Miraflores Lake to the Gatun Lake level. A new single lane of locks 200 feet by 1,500 feet by 50 feet would be added parallel to both Gatun and Miraflores Locks. The channel alinement was to be improved and the channel itself enlarged to 500 feet.[5]

‡The sea-level canal was to follow generally the alinement of the present lock canal. Its cross section was to be 600 feet by 60 feet.

TABLE 2-1

SUMMARY OF SIGNIFICANT PREVIOUS ISTHMIAN CANAL INVESTIGATIONS

Date	Title (Principal Member)	Purpose	Authority	Results
1872-1876	Interoceanic Canal Commission (Brig Gen A.A. Humphries)	To evaluate results of Navy surveys conducted between 1870 and 1875.	Appointed by the President, 15 March 1872.	Recommended construction of a lock canal across Nicaragua.[16]
1876-1879	Societé Civile Internationale du Canal Interocéanique (Lt. L.N.B. Wyse)	To make surveys and investigations for a ship canal in Panama.	Private company with international character.	Explored the Panama, San Blas, Darien and Atrato regions; obtained a long-term construction concession from Columbia.
1878-1889	Compagnie Universelle du Canal Interocéanique (F. de Lesseps)	To plan and construct a sea-level canal in Panama.	Private company.	Excavated an estimated 67,000,000 cubic yards of material; made valuable surveys and maps; produced extensive meteorological records.
1894-1898	Compagnie Nouvelle du Canal de Panama	To construct a lock canal in Panama.	Private company.	Excavated an estimated 11,000,000 cubic yards of material. continued surveys and maintenance of meteorological records.
1899-1901	Isthmian Canal Commission for Exploration 1899-1901 (RAdm J.G. Walker)	To investigate all practical routes for a canal across the isthmus of Panama, particularly the Nicaraguan and Panamanian routes, with a view to construction by the United States.	Act of March 1899, 30 Stat. 1121.	Recommended Nicaragua as the most feasible location for a canal; then in January 1902, reversed its decision to favor Panama after learning the French company had reduced the asking price of its rights and equipment from $109,000,000 to $40,000,000.
1904-1905	Isthmian Canal Commission (RAdm J.G. Walker)	To supervise construction of the canal.	Act of 28 June, 1902, 32 Stat. 481.	Started procurement of materials and supplies; improved living conditions in the Canal Zone.
1905-1907	Board of Consulting Engineers (Maj Gen G.W. Davis)	To consider and recommend the type of canal.	Appointed by the President.	Majority supported sea-level canal; both majority and minority reports submitted to the President.
1905-1914	Isthmian Canal Commission (T.P. Shonts: 1905-1907; J.F. Stevens: 1907; Col G.W. Goethals: 1907-1914)	To supervise construction of the canal.	Act of 28 June, 1902, 32 Stat. 481.	Planned, designed and constructed the Panama Canal. (Excavation amounted to 210,000,000 cubic yards.)

TABLE 2-1

SUMMARY OF SIGNIFICANT PREVIOUS ISTHMIAN CANAL INVESTIGATIONS (Cont'd)

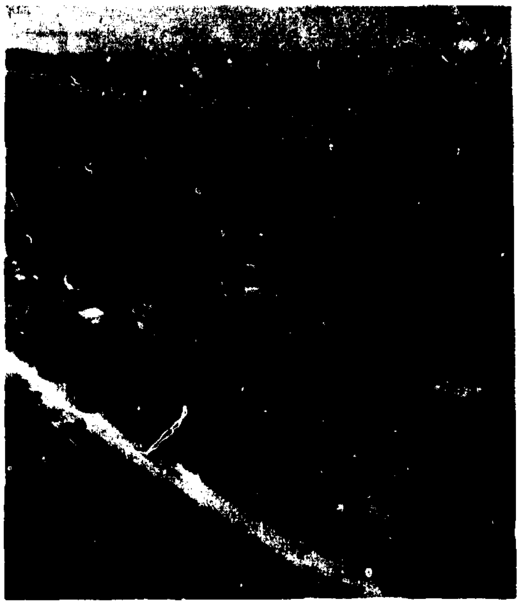
Date	Title (Principal Member)	Purpose	Authority	Results
1929-1931	U.S. Army Inter-oceanic Canal Board of 1929-1931 (Lt Gen E. Jadwin: 1929-1931; Col E. Graves: 1931)	To determine the practicability of providing additional locks and other facilities at the Panama Canal and the practicability of constructing a ship canal elsewhere on the American Isthmus.	Act of 2 March 1929, 45 Stat. 1539.	Recommended that: (1) Madden Dam be constructed; (2) consideration of a canal across Nicaragua be continued; and (3) no immediate steps be taken to provide more facilities to increase traffic capacity.
1936-1939	Third Locks Project Study (Govenor of The Panama Canal)	To study means of increasing the capacity of the Panama Canal, and to propose designs and cost estimates of facilities needed.	Act of 1 May 1936, 49 Stat. 1256.	Recommended construction of a third set of locks, excavation for which began in 1940 and was suspended in 1942.
1945-1947	Isthmian Canal Studies- 1947 (Governor of The Panama Canal)	To investigate the means of increasing the capacity and security of the Panama Canal to meet future needs of inter-oceanic commerce.	Act of 28 December 1945, 59 Stat. 663.	Recommended that the Panama Canal be converted to a sea-level canal.
1949	Special Canal Study - Atrato-Truando route (Governor of The Panama Canal)	To check reliability of surveys of the Atrato-Truando canal route.	Secretary of the Army.	Confirmed the validity of conclusions of 1947 Isthmian Canal Studies regarding the Atrato-Truando route, i.e., that conversion of the Panama Canal to sea-level could be accomplished for less cost.[17]
1957-1960	Ad Hoc Committee for Isthmian Canal Plans (President of the Panama Canal Company)	To determine adequacy of the Panama Canal to meet needs of commerce to 1999, and to recommend plans for improvement if required.	Directed by the Board of Directors of the Panama Canal Company.	Recommended: (1) completion of a major improvement program calling for expenditures of up to $90,000,000; (2) initiation of planning for construction of a sea-level canal outside of the Canal Zone by nuclear methods; (3) development by the AEC of the capacity to construct a nuclear canal; and, (4) planning to construct a sea-level canal in the Canal Zone if plans are not made to construct a sea-level canal by nuclear methods by the early 1970's.

TABLE 2-1

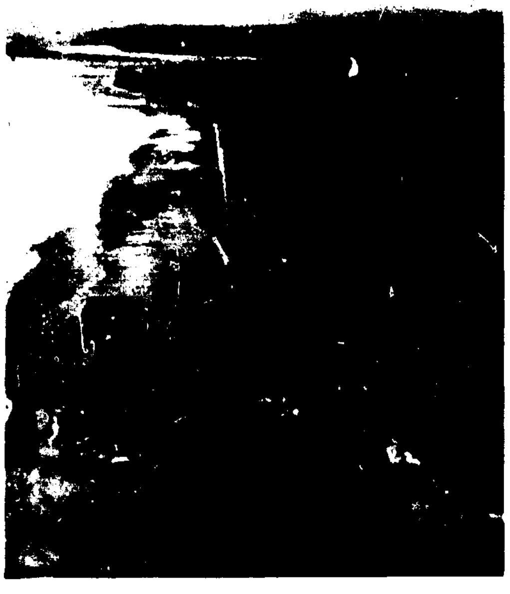
SUMMARY OF SIGNIFICANT PREVIOUS ISTHMIAN CANAL INVESTIGATIONS (Cont'd)

Date	Title (Principal Member)	Purpose	Authority	Results
1957-1960	Board of Consultants, Isthmian Canal Studies (S.C. Hollister)	To investigate short- and long-range plans for the operation, improvement, and other matters relating to the adequacy of the Panama Canal.	Appointed by the Committee on Merchant Marine and Fisheries, House of Representatives (House Resolution 147, 27 February 1957).	Recommended: (1) continued studies of new methods of conventional construction; (2) further development of nuclear excavation; (3) no sea-level canal construction "in the near future"; and, (4) another review of the situation by 1970.
1962-1965	Technical Steering Committee (Col M. Harrison: 1962-1964; Lt. Col W.J. Slazak: 1964-1965)	To establish guidelines of future studies.	Secretary of the Army.	Prepared Plan for Study used for the 1965-1970 study. Updated 1947 cost estimates, and prepared nuclear excavation report for the 1964 studies.[2]
1963-1964	Isthmian Canal Studies, 1964 (President of the Panama Canal Company)	To update traffic projections and plans to meet them and to summarize information on a sea-level canal constructed by nuclear methods.	Directed by the Board of Directors of the Panama Canal Company	Updated previous studies for a sea-level canal, particularly one to be constructed by nuclear means, and presented detailed analyses of plans to improve the existing lock canal, including a third locks plan.
1967-1969	Improvement Program for the Panama Canal - 1969 (A.T. Kearney and Co.)	To develop and test improvement plans to increase capacity of the present canal.	Directed by the Board of Directors of the Panama Canal Company.	Development of a plan which could increase yearly traffic to 26,800 transits.[18]

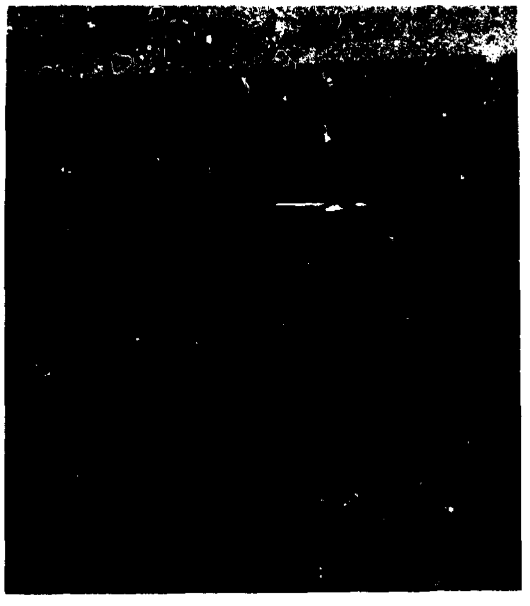
Army LCM unloading supplies at the Curiche Beach Base Camp on Route 25, Colombia. Smaller vessels of this type were used to distribute supplies on the rivers along Route 17.



Road cut through the jungle from the base camp on Saskatupu Island to the weather station established on a nearby mountain.



Aerial view of Curiche Beach Base Camp. Note LCM unloading supplies. The beach was also used as an airstrip for fixed wing aircraft.



Aerial view of the Alto-Curiche weather station established on a jungle hill top on the Pacific side of Route 25.

Since areas under study were very isolated, base camps had to be established at each end of the routes. All supplies were brought in from the Canal Zone.

CHAPTER 3

SELECTION OF ROUTES

The Commission's early efforts were directed to selecting a relatively small number of potential routes for detailed investigation. In the interest of economy and to accomplish its work in a reasonable period of time, the number of routes investigated in detail had to be held to a minimum; yet, no potentially feasible route could be overlooked.

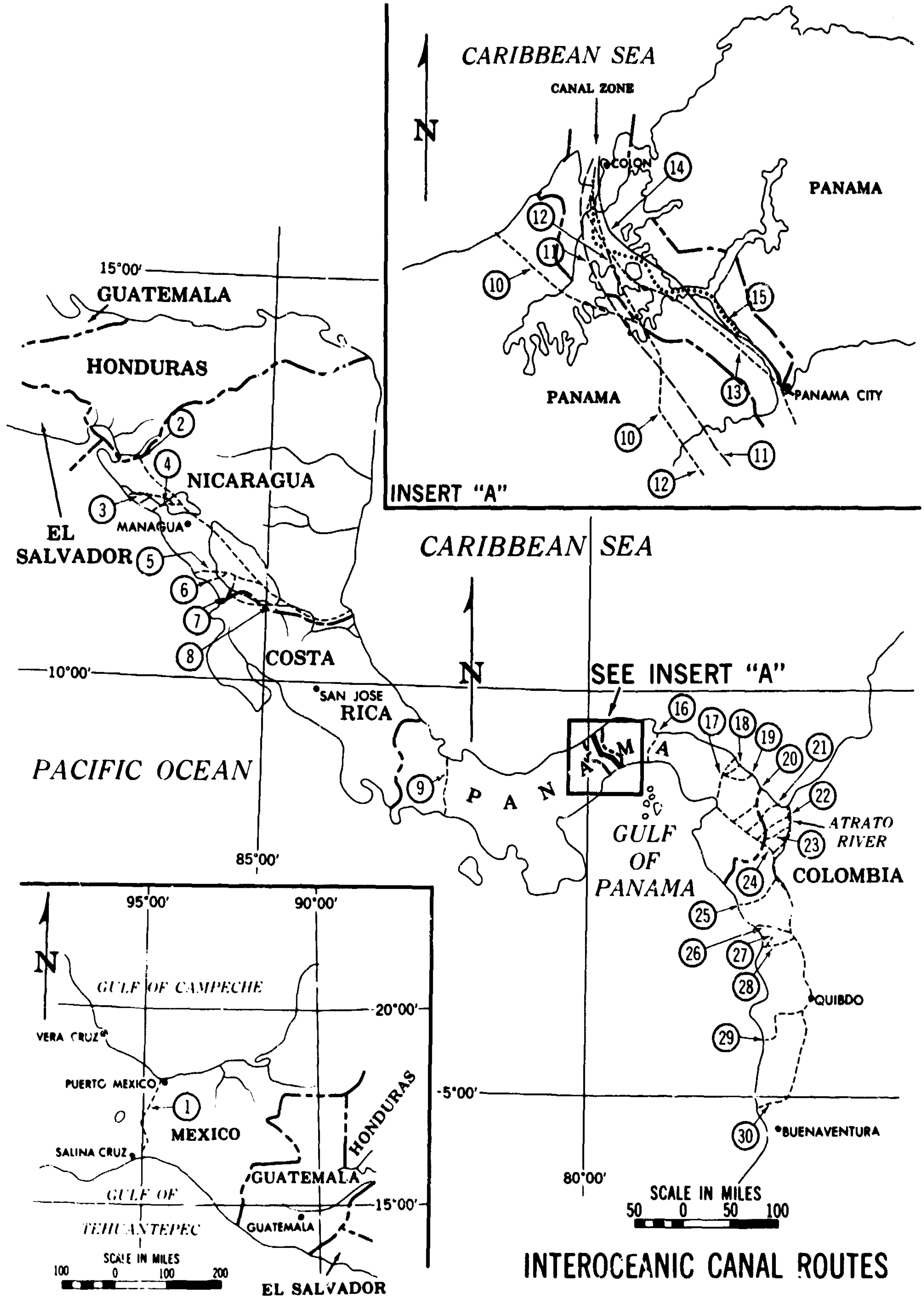
Consideration of routes: At the Commission's first meeting in May 1965, the Secretary of the Army and representatives of the Office of the Chief of Engineers presented recommendations on the preliminary *Plan for Study of Engineering Feasibility,*[2] the organization required for its accomplishment, and the routes to be studied. These recommendations had been prepared by the Technical Steering Committee* organized in October 1962 by the Under Secretary of the Army in response to a Presidential directive that preliminary planning begin for the comprehensive investigation of alternatives to the existing lock canal. This Committee was responsible for developing plans and cost estimates for onsite surveys and engineering studies of sea-level canal routes. It coordinated the participation of the Panama Canal Company, the Corps of Engineers, and the Atomic Energy Commission in the preparation of Annex III† to the 1964 study. That annex identified Routes 17 and 25 as being the most promising for nuclear excavation. The Technical Steering Committee began its work by reviewing recommendations included in the *Isthmian Canal Studies* - 1947, in the 1960 reports of the Board of Directors of the Panama Canal Company, and of the Board of Consultants on Isthmian Canal Studies. Then, between November 1962 and June 1964, the Committee developed a detailed plan for onsite surveys, data evaluation, and engineering analysis of the routes recommended for further study by the 1947 and 1960 reports.[2] These routes were selected from among the thirty presented in the 1947 report, shown on the accompanying map (Figure 3-1) and listed in Table 3-1.

Actions by the Commission: The *Plan for Study* was presented to the Commission on 17 September 1965. As subsequently approved, the plan contemplated investigation of the following alternatives:

- Route 14–The present lock canal alinement in the Canal Zone converted to a sea-level canal by conventional excavation methods and straightened to eliminate turns greater than 35 degrees.

*Membership of the Committee included representatives of the Corps of Engineers, Atomic Energy Commission, and Panama Canal Company.

†*Construction of an Isthmian Sea-Level Canal by Nuclear Methods – 1964.*



INTEROCEANIC CANAL ROUTES

FIGURE 3-1

TABLE 3-1

CANAL ROUTES CONSIDERED BY THE TECHNICAL STEERING COMMITTEE*

MEXICO			1 Tehuantepec
NICARAGUA AND COSTA RICA	VIA LAKE NICARAGUA	VIA LAKE MANAGUA	2 San Juan del Norte–Fonseca Bay
			3 San Juan del Norte–Realejo
			4 San Juan del Norte–Tamarindo
			5 San Juan del Norte–Brito
			6 San Juan del Norte–San Juan del Sur
			7 San Juan del Norte–Salinas Bay
			8 San Juan del Norte–Salinas Bay
PANAMA	ALTERNATIVE SEA-LEVEL ROUTES CANAL ZONE AND VICINITY		9 Chiriqui
			10 Chorrera–Lagarto
			11 Chorrera–Limon Bay
			12 Chorrera–Gatun
			13 Panama Parallel
			14 Panama Sea-Level Conversion
			15 Panama Canal
			16 San Blas
	CALEDONIA BAY ROUTES		17 Sasarda–Morti
			18 Aglaseniqua–Asnati
			19 Caledonia–Surcurti
PANAMA AND COLOMBIA	TUIRA RIVER ROUTES		20 Tupisa–Tiati–Acanti
			21 Arquia–Paya–Tuira
			22 Tanela–Pucro–Tuira
			23 Atrato–Cacarica–Tuira
			24 Atrato–Peranchita–Tuira
COLOMBIA	ATRATO RIVER ROUTES		25 Atrato–Truando
			26 Atrato–Napipi
			27 Atrato–Napipi–Doguado
			28 Atrato–Bojaya
			29 Atrato–Baudo
			30 Atrato–San Juan

*Route numbering based on the 1947 Study.

– Route 17–A sea-level canal through the Darien Province of eastern Panama to be constructed primarily by nuclear excavation methods.
– Route 25–A sea-level canal through northwestern Colombia to be constructed by a combination of nuclear and conventional excavation methods.
– Route 8–A sea-level canal along the Nicaragua-Costa Rica border to be constructed primarily by nuclear excavation methods.*

Initially, funds were sought and approved for field surveys of Routes 17 and 25 only.[3] Data available from previous studies were considered adequate for evaluation of Routes 8 and 14. In 1966 the Commission directed the Engineering Agent to review and update previous cost estimates for improving the existing lock canal (Route 15) and for constructing a new lock canal in Nicaragua (Route 5). These estimates were to provide a base against which the several sea-level canal options could be measured in terms of their capacities and their costs of construction, operation, and maintenance.

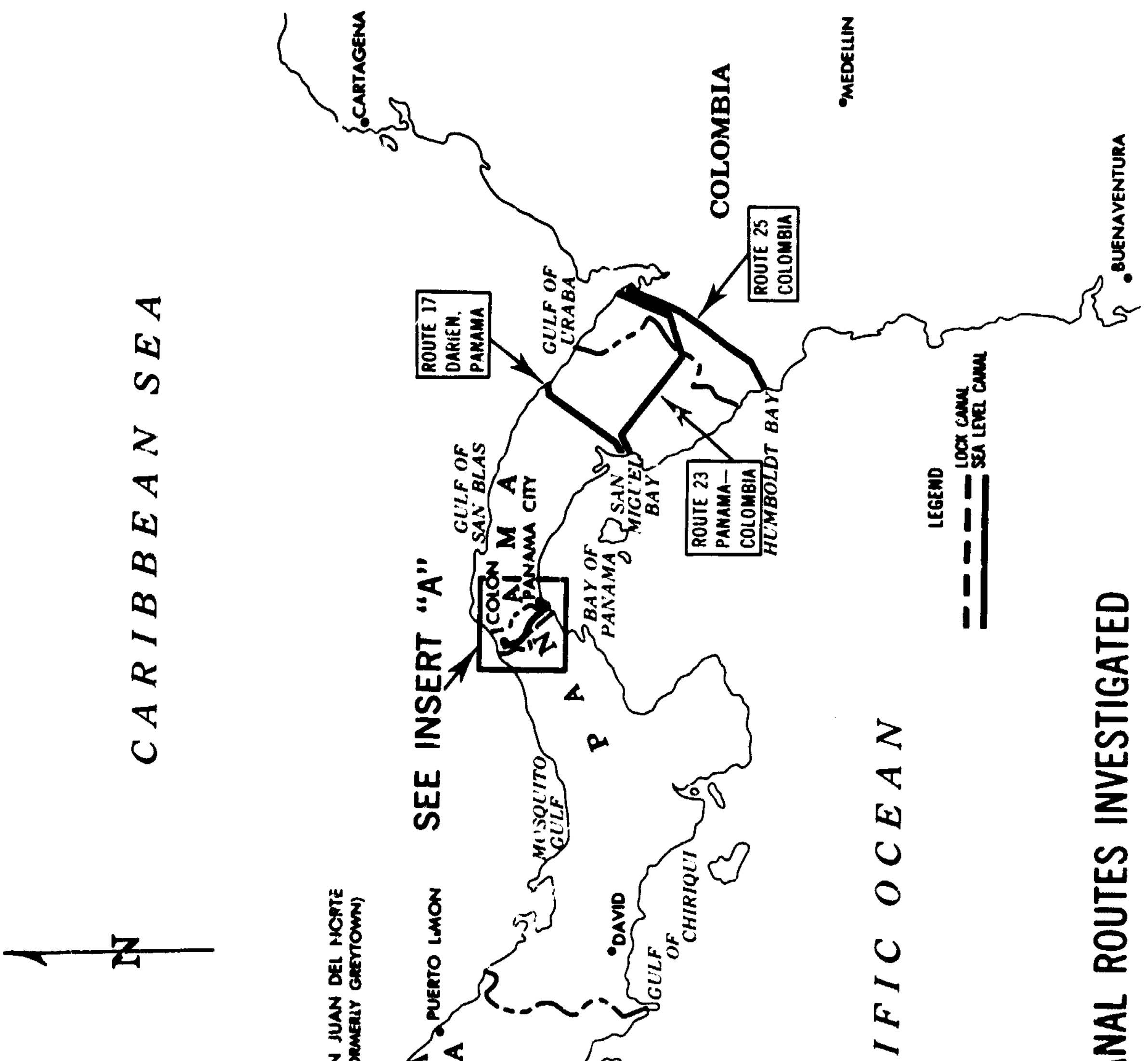
The Commission's preliminary evaluation indicated that a sea-level canal in the vicinity of the existing lock canal, which would not interfere with its operation, might be preferable to Route 14. Consequently, in June 1966, Route 10 was added to the conventionally excavated alternatives and Congress subsequently provided additional funds for its investigation.

In 1969 the Government of Colombia suggested that the United States, Colombia, and Panama investigate Route 23 jointly. The Commission advised Colombian representatives that, although it no longer had the capability to conduct detailed investigations in the field, an analysis of this route, based on available data, would be included in the present report.

Thus, the Commission identified eight potentially feasible routes requiring investigation and evaluation. They are listed below and shown in Figure 3-2.

Route number	Route name	Country	Type of canal/ excavation method
5	San Juan del Norte-Brito	Nicaragua and Costa Rica	Lock/conventional
8	San Juan del Norte-Salinas Bay	Nicaragua and Costa Rica	Sea-level/conventional or nuclear
10	Chorrera-Lagarto	Panama and Canal Zone	Sea-level/conventional
14	Panama Sea-level Conversion	Canal Zone	Sea-level/conventional
15	Panama Canal	Canal Zone	Lock/conventional
17	Sasardi-Morti	Panama	Sea-level/conventional – nuclear combination
23	Atrato-Cacarica-Tuira	Panama and Colombia	Sea-level/conventional or sea-level/conventional – nuclear combination
25	Atrato-Truando	Colombia	Sea-level/conventional – nuclear combination

*The *Plan for Study* recommended only a conceptual study of Route 8, to determine whether additional investigation of this alternative was warranted.



CANAL ROUTES INVESTIGATED

FIGURE 3-2

Since Routes 8*, 14,† and 23 each have two options, 11 basic alternatives were considered in the Study of Engineering Feasibility. These alternatives included two lock canals and nine sea-level canals, four of which would involve nuclear excavation. The principal considerations in their selection are shown in Table 3-2.

*Route 8 Conventional, which follows an angular course to take advantage of low elevations, and Route 8 Nuclear, which is fairly direct.

†Referred to in this study as Route 14 Combined, which cuts through the Continental Divide generally coincident with the present canal; and Route 14 Separate, which cuts through the divide approximately 1 mile southwest of the present canal to minimize the effects of unstable slope conditions on traffic during construction.

TABLE 3-2

INITIAL SCREENING OF PREVIOUSLY IDENTIFIED INTEROCEANIC SEA-LEVEL CANAL ROUTES

Route Number	Route Name	Country	Length (Statute Miles)[a]	Divide Elevation (Feet)[a]	Reasons for Selection/Rejection for Further Study: Sea-Level Canal Conventional Excavation	Sea-Level Canal Nuclear Excavation
1	Tehuantepec	Mexico	165	812	Mexico not receptive; excessive excavation (estimated 6 billion cubic yards)[a].	Mexico not receptive; area moderately populated.
2	San Juan del Norte-Fonseca Bay	Nicaragua and Costa Rica	300	250	Longer than Route 8; requires draining of Lake Nicaragua.	Longer than Route 8; requires draining of Lake Nicaragua.
3	San Juan del Norte-Realejo	Nicaragua and Costa Rica	280	500	Longer than Route 8; requires draining of Lake Nicaragua.	Longer than Route 8; requires draining of Lake Nicaragua.
4	San Juan del Norte-Tamarindo	Nicaragua and Costa Rica	250	200	Longer than Route 8; requires draining of Lake Nicaragua.	Longer than Route 8; requires draining of Lake Nicaragua.
5	San Juan del Norte-Brito	Nicaragua and Costa Rica	177[b]	153	Requires draining of Lake Nicaragua. <u>Selected</u> as a <u>lock canal</u> for comparative purposes.	Requires draining of Lake Nicaragua.
6	San Juan del Norte-San Juan del Sur	Nicaragua and Costa Rica	152	605	Requires draining of Lake Nicaragua.	Requires draining of Lake Nicaragua.
7	San Juan del Norte-Salinas Bay (via Lake Nicaragua)	Nicaragua and Costa Rica	167	760	Requires draining of Lake Nicaragua.	Requires draining of Lake Nicaragua.
8	San Juan del Norte-Salinas Bay	Nicaragua and Costa Rica	176[b] 140[c]	760[b] 1000[c]	<u>Selected</u> for further study as the most favorable in the Nicaragua-Costa Rica area.	<u>Selected</u> for further study as the most favorable in the Nicaragua-Costa Rica area.
9	Chiriqui	Panama	55	5000	Excessive excavation (estimated 69 billion cubic yards)[a].	Excessive divide height.

[a] 1947 values, except where noted; length includes ocean approaches.

[b] Values from 1970 studies.

[c] Nuclear route.

TABLE 3-2

INITIAL SCREENING OF PREVIOUSLY IDENTIFIED INTEROCEANIC SEA-LEVEL CANAL ROUTES (Cont'd)

Route Number	Route Name	County	Length (Statute Miles)[a]	Divide Excavation (Feet)[a]	Reasons for Selection/Rejection for Further Study: Sea-Level Canal Conventional Excavation	Reasons for Selection/Rejection for Further Study: Sea-Level Canal Nuclear Excavation
10	Chorrera-Lagarto	Panama	53[b]	430[b]	*Selected* for further study as comparable in cost to Route 14.	Too close to population centers.
11	Chorrera-Limon Bay	Panama	52	430	More expensive than Route 10 by $0.5 billion[a].	Too close to population centers.
12	Chorrera-Gatun	Panama	50	430	Less favorable than Route 14.	Too close to population centers.
13	Panama Parallel	Panama	50	460	Much more expensive than Route 14[a].	Too close to population centers.
14	Panama Sea-Level Conversion	Panama	54[b]	390[b]	*Selected* for further study as least costly route.[a]	Too close to population centers.
15	Panama Canal (Lock canal only)	Panama	61[b]	Existing channel	*Selected* as lock canal for comparative purposes.	Too close to population centers.
16	San Blas	Panama	40	1100	Twice as much excavation as for Route 14 because of high divide.	Too close to population centers.
17	Sasardi-Morti	Panama	77[b]	1000[b]	About twice as much excavation as Route 14.	*Selected* for further study as most favorable nuclear route in Panama.
18	Aglaseniqua-Asnati	Panama	63+	1100	More excavation and poorer alinement than Route 17.	Poorer alinement than Route 17.
19	Caledonia-Sucurti	Panama	63+	720	More excavation and poorer alinement than Route 17.	Poorer alinement than Route 17.

[a]1947 values, except where noted; length includes ocean approaches.

[b]Values from 1970 studies.

TABLE 3-2

INITIAL SCREENING OF PREVIOUSLY IDENTIFIED INTEROCEANIC SEA-LEVEL CANAL ROUTES (Cont'd)

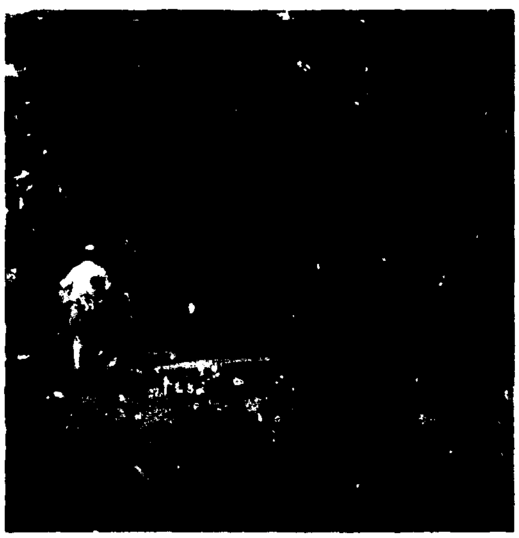
					Reasons for Selection/Rejection for Further Study	
Route Number	Route Name	Country	Length (Statute Miles)[a]	Divide Elevation (Feet)[a]	Sea-Level Canal, Conventional Excavation	Sea-Level Canal, Nuclear Excavation
20	Tupisa-Tiati-Acanti	Panama and Colombia	96	1200	Almost three times the excavation required on Route 14	Longer than Route 17.
21	Arquia-Paya-Tuira	Panama and Colombia	136	1500	Excessive excavation because of length and high divide.	Length and divide elevation excessive.
22	Tanela-Pucro-Tuira	Panama and Colombia	130	1500	Excessive excavation because of length and high divide.	Length and divide elevation excessive.
23	Atrato-Cacarica-Tuira	Panama and Colombia	146[b]	450[b]	*Selected* for limited study at the request of Colombia.	*Selected* for limited study at the request of Colombia.
24	Atrato-Peranchita-Tuira	Panama and Colombia	133	957	About twice the excavation required on Route 14; poor alinement.[a]	Less attractive than Route 17 because of length and cost.
25	Atrato-Truando	Colombia	103[b]	932[b]	About twice as much excavation as Route 14.	*Selected* as the most favorable Atrato River route.
26	Atrato-Napipi	Colombia	137	595	About twice as much excavation as Route 14.	Less favorable than Route 25.
27	Atrato-Napipi-Doguado	Colombia	140	778	Greater excavation than Route 26.	Less favorable than Route 25.
28	Atrato-Bojaya	Colombia	153	778	Greater excavation than Route 27.	Less favorable than Route 25.
29	Atrato-Baudo	Colombia	261	1000	Greater excavation than Route 28.	Less favorable than Route 25.
30	Atrato-San Juan	Colombia	344	379	Greater excavation than Route 29.	Less favorable than Route 25.

[a]1947 values, except where noted; length includes ocean approaches.

[b]Values from 1970 studies.

Radar equipment for the meteorology program, shown here atop Pidiaque Hill in Panama, was shipped in from the United States. Supplies for the station's operation were delivered by helicopter.

A subsurface drilling rig in the jungle on Route 25. Drill sites were hacked out of the jungle and their equipment brought in by helicopter. Supplies were flown in and the core samples were flown out.



Generators such as this supplied the power necessary for the radar stations. All fuel and supplies came through the Canal Zone.

The U.S. Air Force provided helicopter support when possible. Helicopter is preparing to deliver a load of equipment to a jungle drilling site.

The jungle areas investigated imposed unusual problems of transportation and supply.

CHAPTER 4

CHARACTERISTICS OF THE REGIONS UNDER STUDY

The canal routes evaluated in this study traverse four regions, each of which has distinctive physical characteristics:

- Nicaragua-Costa Rica Border (Routes 5 and 8).
- Panamanian Isthmus (Routes 10, 14 and 15).
- Darien Isthmus (Routes 17 and 23).
- Atrato-Truando (Routes 23 and 25).

The Nicaragua-Costa Rica border region (Routes 5 and 8): The dominant terrain feature of this area is Lake Nicaragua, whose surface elevation is approximately 105 feet above sea level. It is about 100 miles long, and nearly 45 miles across at its widest point; its maximum depth is over 200 feet. Lake Nicaragua is fed by the Tipitapa River, the outlet of Lake Managua, and drained by the San Juan River which discharges into the Atlantic Ocean, some 80 miles away. The distance between the Atlantic and Pacific Oceans depends upon the route, varying from approximately 125 to 170 miles.

The Continental Divide between Lake Nicaragua and the Pacific Ocean is a low, narrow ridge with a minimum elevation of about 150 feet, the divide's lowest point in Central America. East of Lake Nicaragua other ridges separate the lake's drainage basin from the Caribbean. This so-called East Divide, which is generally higher than 400 feet, is broken by the San Juan River which passes through it below elevation 100 feet.

Both the eastern and western ridges consist mainly of extrusive igneous rocks with some sedimentary bedrock, underlying a thin layer of overburden. The delta of the San Juan River is composed of alluvial deposits reaching depths of 100 to 200 feet or more. The region contains a number of active volcanoes. Upland soils are predominantly lateritic. Vegetation includes both evergreen and deciduous trees, and is classified as tropical moist forest.

The climate of the Nicaragua-Costa Rica region is tropical. Temperatures seldom exceed 95°F or fall below 70°F. Rainfall averages about 250 inches a year on the Atlantic coast, decreasing to about 60 inches on the Pacific. There is a dry season from November to May on the Pacific side; on the east coast seasonal changes are less distinct. East of the lake humidity remains high throughout the year; to the west it falls off considerably during the dry season. Prevailing surface winds are 10 to 15 miles per hour from the northeast. Pacific tides are semidiurnal with an average range of 6.2 feet and a maximum of 9.7 feet. Tides on the Atlantic coast are irregular, having an average range of 0.7 feet and a maximum of 2.6 feet.

NICARAGUA-COSTA RICA BORDER AREA

SCALE IN MILES

10 0 10 20 30

DEPTH IN FATHOMS

FIGURE 4-1

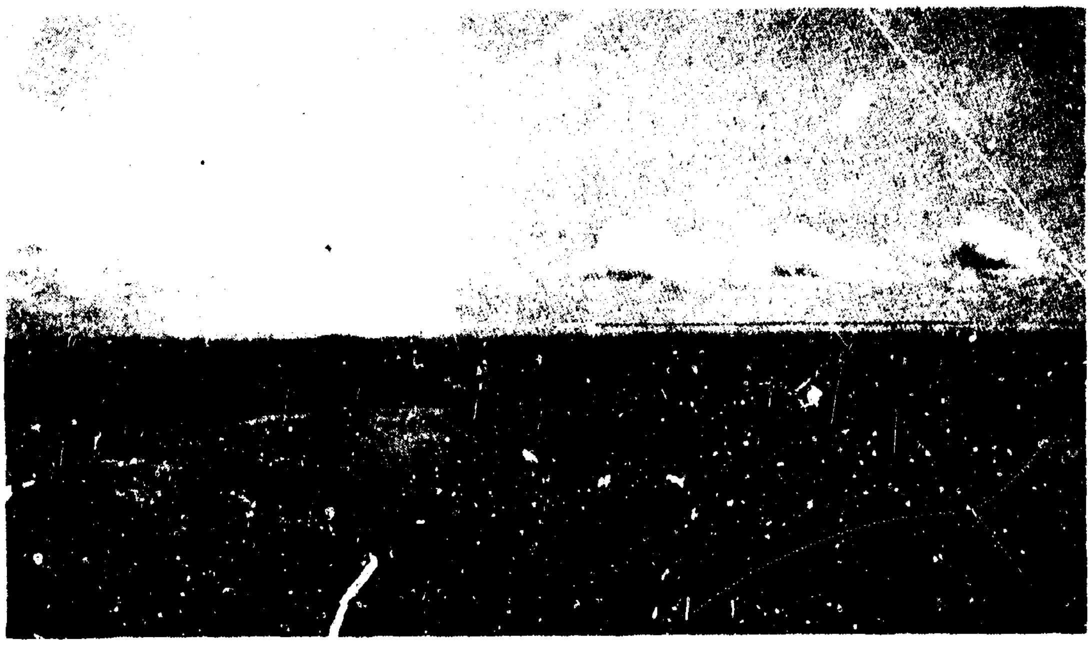
The Caribbean coast, looking north, at the site of the Atlantic terminus of Route 8. The town of San Juan del Norte is at the right of the picture.

The confluence of the San Carlos (left) and San Juan (right) Rivers.

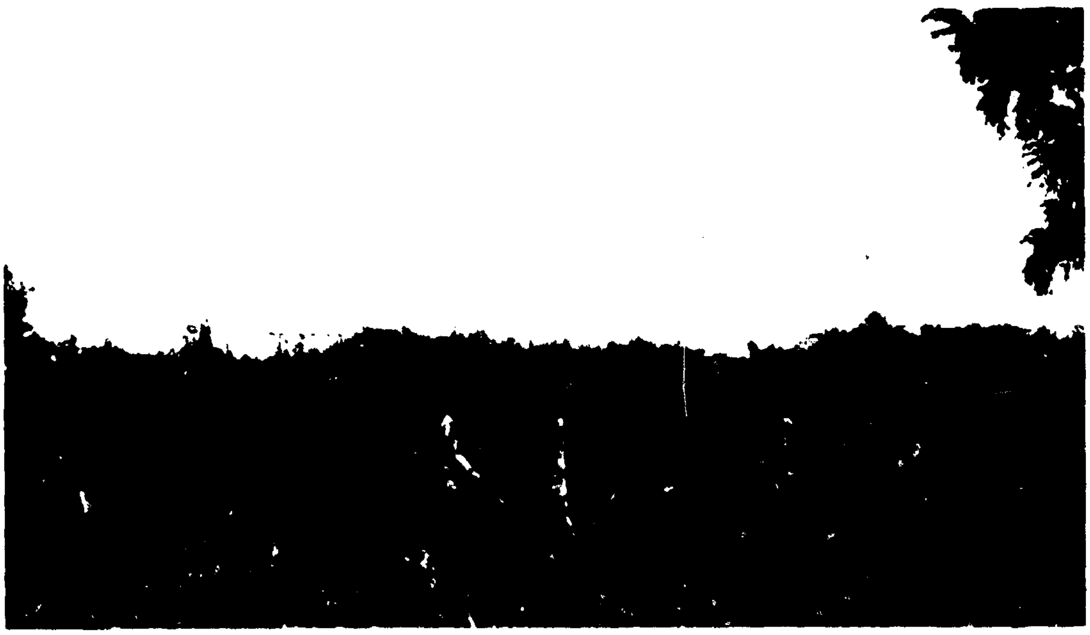
The Pacific shoreline, looking north, in the vicinity of Route 5.

THE NICARAGUA-COSTA RICA BORDER AREA

FIGURE 4-2



The southeastern shore of Lake Nicaragua at the headwaters of the San Juan River.



The cloud shrouded volcano Concepcion as seen from the Pan American Highway.

NICARAGUA-COSTA RICA BORDER AREA

FIGURE 4-3

The mouth of the Sapoa River on the south shore of Lake Nicaragua.

Railcar on a pier at Granada on Lake Nicaragua.

NICARAGUA-COSTA RICA BORDER AREA

FIGURE 4-3

East of Lake Nicaragua the area traversed by the canal alinements is largely undeveloped. It is covered by thick jungle with only a few small clearings devoted to crops and grazing. Population density in this area is about five inhabitants per square mile. The divide, its immediate western slopes, and the shores of Lake Nicaragua are more heavily populated and developed, averaging about 25 inhabitants per square mile. The principal industries and population centers of both Nicaragua and Costa Rica lie approximately 100 miles away from the proposed canal routes. Most of Costa Rica's 1.7 million people are located in the region near San Jose, while three-quarters of Nicaragua's population of 1.9 million live near the shores of Lake Nicaragua and Managua.

The population in the area that would be affected by canal excavation is primarily mestizo, with small percentages of Caucasians, Negroes and Indians. The literacy rate is low and health and sanitation standards are poor. Construction would not adversely affect primitive cultures having anthropological value.

Most archeological finds in the area of southern Nicaragua and western Costa Rica have been on the Pacific slopes adjacent to Lake Nicaragua. Numerous stone statues up to four meters in height have been noted on the shores and islands of the lake.[19] Northwestern Costa Rica also appears archeologically rich; however, the most spectacular artifacts, such as jade and gold objects, come from looted and undocumented sites. Since a canal would generally follow natural drainage systems, it would cross areas of high archeological potential, which are most often found clustered along rivers and other natural sources of water. To date, nevertheless, there have been no major archeological finds in the immediate areas of the proposed routes.

Existing shipping facilities capable of serving a canal are extremely limited. On the Pacific side, deep water lies between ½ and 3 miles from the coast. On the Atlantic, cargo vessels are unable to approach closer than about 3 miles from shore in the vicinity of the routes. The principal Pacific ports are Corinto, Nicaragua, and Puntarenas, Costa Rica. Both of these ports could accommodate modern cargo vessels; however, they are too far from the routes to serve as supply bases. Only the shallow draft* harbors at Bluefields, Nicaragua, and Puerto Limon, Costa Rica, are available on the Atlantic side.†

The Panamanian Isthmus (Routes 10, 14, and 15): In this area the American Isthmus is both narrow and low. The distance between oceans here is approximately 30 to 60 miles, depending on the alinement. For Routes 14 and 15 the valley of the Chagres River, now largely submerged beneath Gatun Lake, offers an easy approach from the Atlantic Ocean to the Continental Divide through which there are passes at elevations of approximately 300 feet.

The geology of the area is complex and characterized by abrupt transitions from competent rock to materials of very low strength. The terrain on the Pacific side, which includes the Continental Divide, is dominated by conical hills, capped by basalt or agglomerate and surrounded and underlain by weak sedimentary and pyroclastic rocks.

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*These harbors are capable of handling vessels at 12-foot draft or less.

†Limited small boat facilities exist at the Nicaraguan towns of San Juan del Sur on the Pacific and San Juan del Norte on the Atlantic

THE CANAL ZONE AND VICINITY

FIGURE 4-4

SCALE IN MILES

5 0 5 10

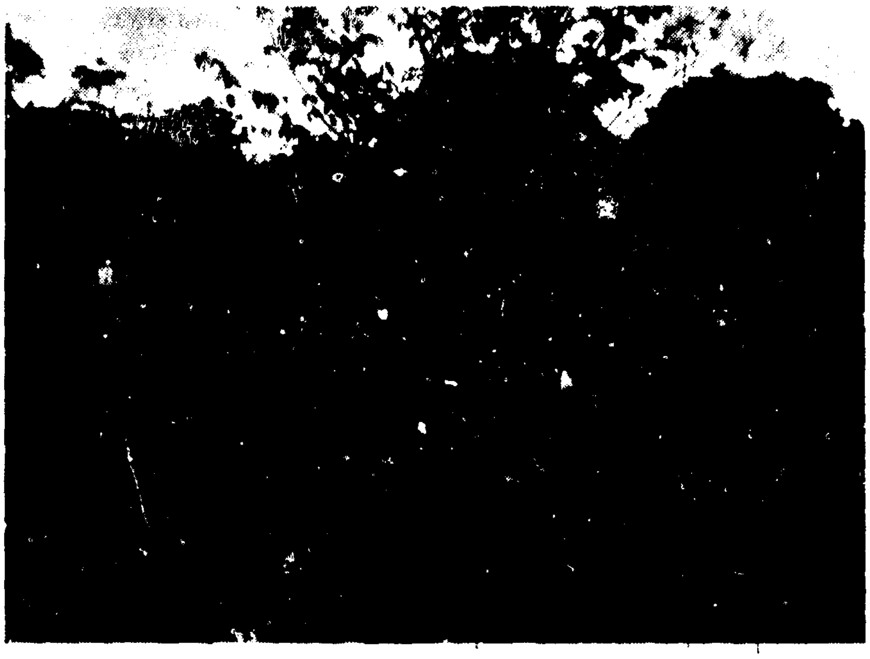
DEPTH IN FATHOMS

The Caimito River and Pacific coastline, looking southeast from the proposed Route 10 terminus.

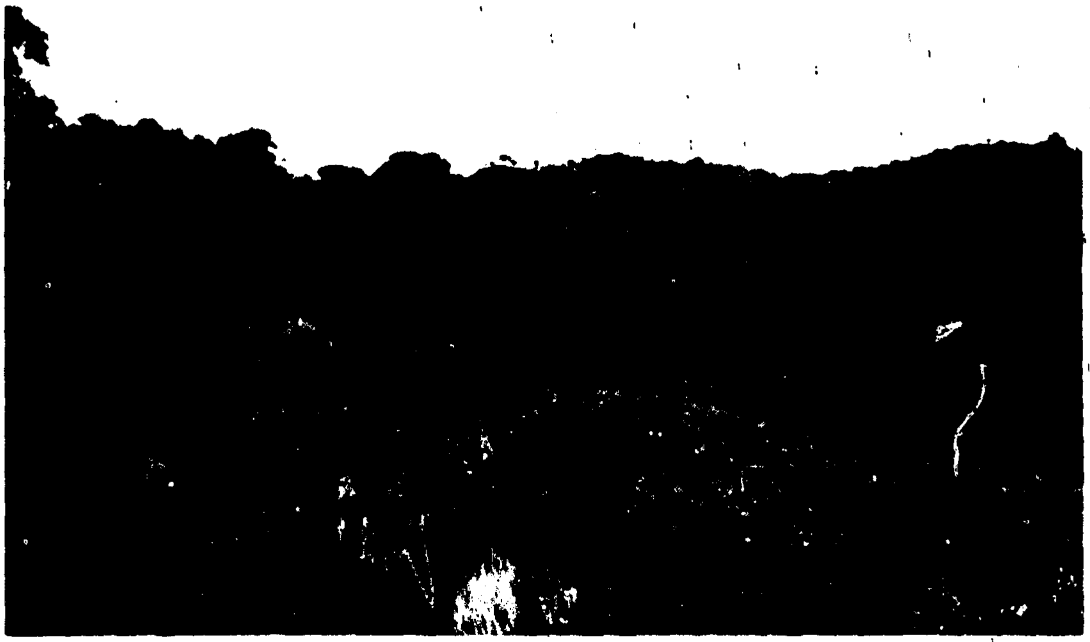
Looking northeast along the Pan American Highway from the vicinity of the alinement. The bridge in the foreground crosses the Caimito River.

ROUTE 10 AREA

FIGURE 4-5



Typical bohios in the village of Rio Congo, a settlement northeast of the alinement and near the Continental Divide.



The alinement immediately north of the Continental Divide, looking northeast.

ROUTE 10 AREA
FIGURE 4-5

Materials in the central sector of this area vary from weak clay shales and soft altered volcanics to relatively stronger sandstones and basalts. The ridges along the Atlantic coast consist of medium hard sandstones.

Soils in this portion of the Isthmus are predominantly lateritic. The scattered cleared areas exhibit the developmental pattern typical of shifting subsistence agriculture. Most of the ground is covered by a tropical moist forest with a multi-storied canopy. Small areas of savanna are found in the southern portion and premontane evergreen forest* occupies the upland and divide areas.

The climate is tropical with temperatures averaging 83°F and ranging between 65°F and 95°F. Mean relative humidity is 80 percent. A distinct rainy season extends from mid-April to mid-December. Annual rainfall varies from 130 inches on the Atlantic coast to 70 inches on the Pacific. Occasionally winds on the Atlantic side cause hazardous seas.

Tides in the Atlantic are irregular, with an average range of 0.7 feet and a maximum of 2.6 feet. Pacific tides are semidiurnal, having an average range of 12.7 feet and a maximum recorded range of 21.7 feet.

The urban centers, Panama City (population 415,000) and Colon (population 85,000), are situated at the ends of the Panama Canal and are linked by a railroad and two-lane highway. Both cities are close to excellent harbor facilities operated by the Panama Canal Company–Cristobal on the Atlantic side and Balboa Harbor on the Pacific. Essential ship services, such as repair and bunkering, are available.

The area lying west of the Canal Zone along Route 10 has undergone moderate development. The rolling hills on the Pacific side of the Continental Divide have been cleared of the tropical jungle which once covered the entire Isthmus. This region and the Caribbean coastal area are used for farming and grazing. Further inland the area is covered with jungle growth, broken only by a few clearings given over to slash-and-burn cultivation. Most of the land along the alinement is publicly owned. La Chorrera (population 38,000) on the Pan American Highway is the only significant town in the vicinity of Route 10.

Two-thirds of Panama's population are mestizos. The rest is made up of Indians, Negroes, Caucasians and Asiatics. The predominant cultural heritage is Spanish. The area within and immediately surrounding the Canal Zone contains remains which span much of American prehistory, the earliest local manifestations of which appear in the "fishtail" fluted projectile points from Madden Lake.[20] These may be part of the general Paleo-Indian horizon of the Americas, dated from remains found elsewhere to around 7000 B.C. and earlier. A recent project has revealed at Panama Viejo a culture based largely on fishing and shellfish gathering–a "rather widespread group of related tribes....distributed over the Canal Zone, and Pearl Islands, and adjacent territory to the east."[21] The relationship of this culture to others from western Panama–the Venado Beach culture (tentatively dated as about 1000 years old) and the Cocle manifestation of late prehistory–is not yet known. Undoubtedly, other sites lie within the area under consideration.

The Route 10 alinement is readily accessible from the Canal Zone. Roads exist between Panama City and La Chorrera, and between Colon and Lagarto. Gatun Lake offers a good means of access to the hinterland. Apart from the Panama Canal terminals, coastal harbor facilities are extremely limited.

*This is a low dense evergreen forest with abundant epiphytes (parasitic moss, lichens, orchids, etc.).

The Darien Isthmus of Panama (Routes 17 and 23): Very little information on this area was available prior to the present study. Some topographic and geologic data were obtained from the Isthmian Canal Commission Studies of 1899-1901, from geological reconnaissance in 1946-47 and from recent aerial photography; however, they were not adequate to permit evaluation of the feasibility of constructing a canal. Consequently, the Commission undertook a program of field surveys in the vicinity of the Route 17 alinement. The results obtained from this program, conducted in the period 1966-1969, are summarized in Table 4-1. These data apply only indirectly to Route 23.

TABLE 4-1

DATA COLLECTION PROGRAM IN THE DARIEN REGION, 1966-1969

Topography	A 57-mile baseline survey was made. More than 200 miles of cross section were surveyed.
Geology	Geologic reconnaissance included surveys of an area of more than 290 square miles. Subsurface exploration consisted of 20 holes, totaling about 12,000 feet of core drilling. Material was tested in place by geophysical methods and borehole photography. More than 450 samples were subjected to laboratory testing for paleontologic, petrographic, chemical, and physical characteristics.
Hydrology	Fourteen rainfall, 5 stream, 2 sediment and 2 tide gages were installed, and records were obtained from November 1966 to October 1968.
Meteorology	Two weather stations were established, one near each end of Route 17; surface and upper air observations were made from July 1966 to December 1967.
Medico-Ecology	Insect and animal specimens were collected and identified from this study area and the Atrato-Truando region of northwestern Columbia in 1967; blood of specimens was analyzed to determine vectors and reservoirs of human disease.
Bioenvironment	Native populations were studied to determine living habits and agricultural systems. Plants and animals, both marine and terrestrial, were studied to determine their relation to human food chains.
Acoustic waves	Atmospheric conditions were measured up to 200,000 feet, with wind speed, direction and temperature being measured by an average of 5 instrumented rockets per week launched from Battery McKenzie in the Canal Zone. Windowpane surveys were made.
Ground motion	A network of 10 seismographs was installed (2 in Panama, 8 in Columbia) and operated from June 1967 to March 1969. Structural surveys were made in major population centers.

View, looking northwest, across Limon Bay from Colon, Panama. The Atlantic entrance to Route 14 would be through Limon Bay.

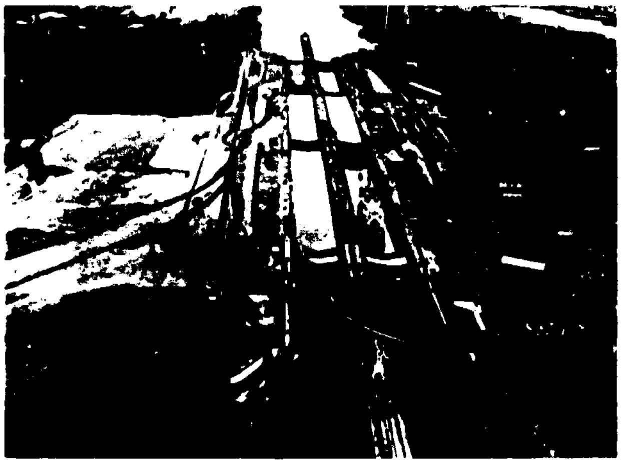
The Route 14 alinement, looking northwest, Cerro Gordo is the left background; the Panama Canal is on the right.

ROUTE 14 AREA
FIGURE 4-6

View of the proposed Pacific entrance of Route 14, looking south from Balboa toward the Thatcher Ferry Bridge. The bridge is a major link in the Pan American Highway.

View across Miraflores Lake, looking northwest. Miraflores Locks, shown in the foreground, raise and lower ships 54 feet in 2 steps. The Pedro Miguel Locks are in the background.

ROUTE 14 AREA
FIGURE 4-6



Almost a mile long, the Gatun Locks permit ships to be raised or lowered approximately 85 feet in three steps. Here two ships are being locked up into Gatun Lake. The dredged channel in the background leads to the Caribbean Sea.

The battleship New Jersey passing through the Pedro Miguel Locks enroute to Vietnam in 1968. The New Jersey is one of the largest naval vessels to transit the canal. Most modern aircraft carriers are too large to use the canal.

Approximately 8 miles long, Gaillard Cut produced most of the major problems encountered during the construction of the Panama Canal. The cut widening shown in this view, looking southwest along the canal, is now complete.

PANAMA CANAL AREA
FIGURE 4-7

The Darien region's remoteness from major population centers, its narrow width and relatively low elevations along the Continental Divide make it attractive for the employment of nuclear excavation techniques. Indeed, it was these features of Route 17 that brought about the present study.

The Continental Divide lies about 10 miles west of Caledonia Bay. Most of the low passes in this area are too narrow to accommodate a sea-level canal; however, Sasardi Pass at an elevation of about 1,000 feet appears suitable for nuclear excavation. In the central sector the Chucunaque River, its tributaries and the Sabana River flow southeasterly through a valley about 20 miles wide, with an average elevation of about 200 feet. This valley is separated from the Gulf of San Miguel on the west coast by the Pacific Hills, through which the best canal alinement would pass at an elevation of 750 feet.

The Continental Divide consists largely of basaltic flows with pyroclastic interbeds, while material in the Chucunaque Valley is mainly weak clay shales. The Pacific Hills, a series of anticlinal ridges and fault blocks, are formed of basic volcanic rocks and calcareous tuffs.

Along the eastern edge of the Darien region, coinciding with the Panama-Colombia border, the Continental Divide crosses from the Atlantic to the Pacific side of the Isthmus. Relatively low divide elevations can be found between the headwaters of the Tuira River, flowing northwesterly to the Gulf of San Miguel, and the Cacarica River, flowing easterly to the Atrato River. Although surveys of this area have been very limited, it is generally believed that the lowest divide elevations here are between 400 and 500 feet.

Data available from previous investigations and a geological reconnaissance conducted in support of this study, indicate that the divide in this sector is composed of tuffs, limestone, and interbedded sandstone and shales. Except for a short reach of Pacific tuffs near La Palma, the lower Tuira River flows mostly through sedimentary formations, overlain near the coast by marine swamp deposits.

The Darien's climate is essentially the same as that of the Canal Zone. Annual rainfall averages about 100 inches at the Atlantic coast, 120 inches along the Continental Divide and 80 inches at the Pacific.

The area is generally covered by heavy tropical jungle. There are four major types of forest in Panama and all may be found in the Darien Isthmus. The predominant cover is tropical moist forest typified by a tall deciduous canopy over a stratum of evergreens and palms. Bordering the marshy areas of the Gulf of San Miguel are mangrove forests. River valley flood plains support hardwood forests, principally of cativo. In the area of the Continental Divide and other scattered uplands the vegetative cover is classed as premontane wet forest.

Soils in the vicinity of Route 17 are primarily lateritic, except in the Chucunaque River Valley where the soils are generally alluvial. The Caribbean coastline is bordered by a narrow strip of beach sands while the Pacific side of the isthmus consists of marsh-type soils.

Atlantic tides are irregular, with a mean range of 1.0 foot and a maximum of 2.7 feet. Approaches to the Atlantic shore are exposed to storms and there are no natural harbors or port facilities, although some local protection is provided by the irregular coastline and the islands in Caledonia Bay. Deep water lies about 2 miles offshore.

The Pacific terminus is within the Gulf of San Miguel. La Palma provides some port facilities, as well as navigable depths for shallow draft shipping. Although there is deep water

PANAMA-COLOMBIA BORDER AREA

SCALE IN MILES

5 0 5 10 15 20 25 30 35

DEPTHS IN FATHOMS

FIGURE 4-8

within ½ mile of the shoreline, there are many shallow areas which would have to be dredged for an approach channel. Tides there are semidiurnal, with a mean range of 14.3 feet and an estimated maximum range of 23.0 feet.

Inhabitants of the Darien region include several ethnic groups. La Palma, the capital of Darien Province, is a coastal town of about 1,500 people of mixed origin. Inland, on the Pacific side, primitive Choco Indians live in family units. Isolated Cuna Indian villages dot the interior river valleys on the Atlantic side. The Cunas also inhabit many of the San Blas Islands along the Atlantic coast, traveling to the mainland to farm, hunt, and obtain fresh water.

The Panamanian government has a special agency to deal with the San Blas Cunas, whose culture has been thoroughly studied. The interior Cunas avoid strangers and relatively little is known about their culture and tribal organization. Hostility to the white man has been passed from generation to generation since the time of the conquistadores. Both the San Blas and interior Cunas could be expected to resist any efforts to move them in order to permit canal construction. The Choco Indians might be more amenable to such a shift.

Little is known of the archeology of the Darien Isthmus. The area appears to have been thickly settled and prosperous at the time of the conquest;[19] however, there have not yet been any major archeological finds in the immediate areas of the proposed routes.

The Atrato-Truando region of northwestern Colombia (Routes 23 and 25): The 1947 Isthmian Canal Studies made it a rent that more information on the Colombian routes was needed. Consequently, the *Special Canal Study - 1949* was conducted to collect data on topography, geology, and climatic conditions.[17] This effort, together with a number of independent reports, provided background material for planning the present study. To permit evaluation of Route 25, field surveys were made, similar to those along Route 17. This work was performed during the period 1967-1969. Its results are summarized in Table 4-2.

The American Isthmus in the Atrato-Truando region of the Choco Province of northwestern Colombia is characterized by high, rugged terrain within sight of vast estuarine marshes. Because of its remote location and the relative ease and low cost of dredging lowland swamp areas, it holds promise for the application of a combination of nuclear and conventional construction techniques. Here the distance between the Atlantic and Pacific is approximately 100 miles. The dominant terrain feature is the Atrato River which flows through the northern half of the region from its confluence with the Truando River to the Gulf of Uraba on the Atlantic. The Continental Di e lies on the Pacific side, in mountainous terrain nearly 20 miles wide, through which there are passes at elevations between 900 and 1,000 feet. The Curiche River has its headwaters in the divide highlands and flows westward for about 20 miles before emptying into Humboldt Bay on the Pacific.

Soils in the upper Tuira River Valley and along the Continental Divide separating Panama and Colombia are primarily lateritic. The Atrato Valley is a broad plain composed of marsh-type soils. The Choco Highlands, which form the Continental Divide in this region, are high, narrow ridges formed by the uplifting of Choco volcanic rocks. Soils are lateritic and tend to be shallow.

The upland areas of the divide and the extensions of the Choco Highlands are primarily covered with dense, low evergreens intermixed with abundant epiphytes and woody vines.

Typical view of the Pacific coastline, looking west, near the proposed Pacific entrance to Route 17.

View along the Continental Divide, looking south.

ROUTE 17 AREA
FIGURE 4-9

Chucunaque Valley centerline trail from Santa Fe built for the data collection program.

Typical Cuna village in remote jungle near the Route 17 alinement.

ROUTE 17 AREA
FIGURE 4-9

TABLE 4-2

DATA COLLECTION PROGRAM IN THE ATRATO RIVER REGION

Topography	A 78-mile baseline survey was made from the Pacific to the Atrato River. About 160 miles of cross sections were surveyed.
Geology	Aerial mapping of surface geology included geophysical surveys of an area of about 540 square miles. Sub-surface exploration consisted of 22 holes with an aggregate footage of about 9,000 feet. Material was examined in place by downhole geophysical methods and borehole photography. More than 300 samples were tested to determine paleontologic, petrographic, chemical, and physical characteristics.
Hydrology	Eighteen rainfall gages, 8 stream gages, and a tide gage (on the Pacific) were installed and records obtained from July 1967 to December 1968. Six combination stream and rain gages were operated until May 1969.
Meteorology	Two weather stations – one near each terminus of the route – were established. Surface and upper air observations were made from July 1967 through June 1969.
Medico-Ecology, Bioenvironment, Acoustic waves, Ground motion	Field data collected and discussed previously in relation to the Darien Isthmus of Panama are also applicable to this study area.

The principal remaining forests are located on rolling hills between the Atrato flood plain and uplands and consist of multi-storied hardwoods. The flood plain itself is covered with tall grasses, cane-like palms and brush-type plants that form impenetrable thickets.

The tropical climate is generally similar to that of the other routes. Average annual rainfall varies from 80 inches at the Gulf of Uraba to 200 inches on the Pacific side.

Atlantic tides are irregular, with a mean range of 1.1 feet and a maximum of 2.9 feet. Pacific tides are regular, having a mean range of 8.4 feet and an estimated maximum of 14.0 feet.

This region is even less developed than the Darien Isthmus of Panama. Within the area which would be affected by a sea-level canal, the Atrato Swamp is generally uninhabited; an exception is the village of Rio Sucio. Near the Continental Divide are occasional clearings along the streams where Choco Indians have settled. Selective lumbering for mahogany is carried on in this region.

The only harbor facilities on the Atlantic side are at the Caribbean port of Turbo, Colombia. The channel there is maintained at 12 feet, with 10-foot depths available along harbor piers. Deep water lies about 4 miles away from the port. Navigation on the Atrato River is presently restricted to shallow-draft vessels. On the Pacific, Humboldt Bay provides

a natural roadstead. Deep water is found within 1½ miles of the coast. The Pacific beach slopes gently and during low tides can be used as a landing strip for helicopters and small fixed-wing aircraft.

Most inhabitants of the areas affected by the proposed canal are either mestizo or Negro. The two major Indian groups, Choco and Cuna, are slowly being assimilated by these relative newcomers or are moving toward the mountains of Panama. Canal construction could be expected to make a drastic change in the Indian way of life.

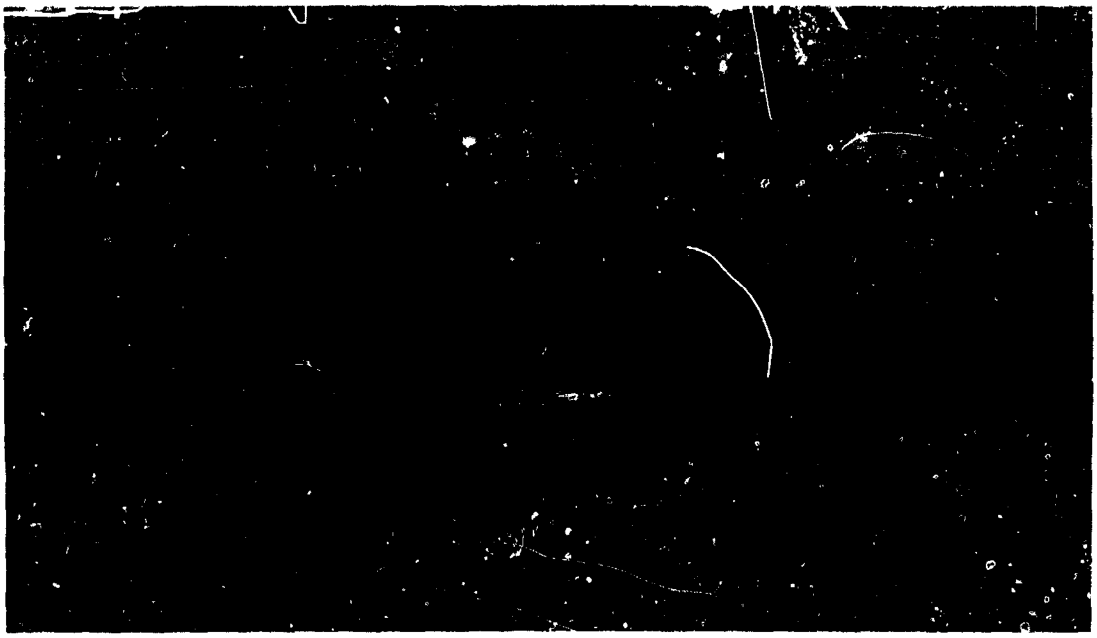
Little is known of the archeology of this region. To date, no significant finds have been made; however, if a canal were built, it would probably follow natural drainage patterns where such finds are most likely to occur.

Summary table: Characteristics of these four regions are summarized in Table 4-3.

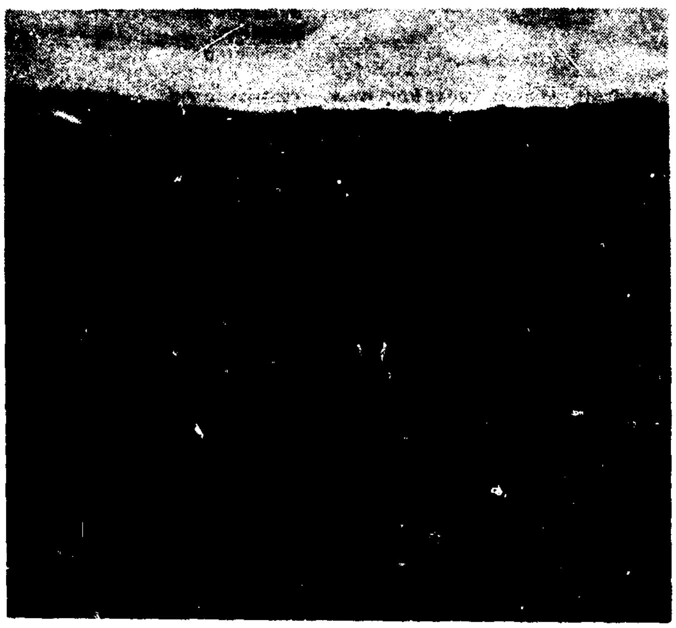
Atrato River delta and proposed Atlantic terminus of Route 25, looking north.

The Teresita base camp on the banks of the Truando River, used for data collection.

ROUTE 25 AREA
FIGURE 4-10



Loma Teguerre weather station located near the Atlantic end of Route 25. Station was built on one of the few high points of land in the Atrato low lands.



Continental Divide area looking east from Alto Curiche weather station. The light spot at left center is smoke from burning off a site for subsurface geologic investigations during data collecting activities.

ROUTE 25 AREA
FIGURE 4-10

TABLE 4-3

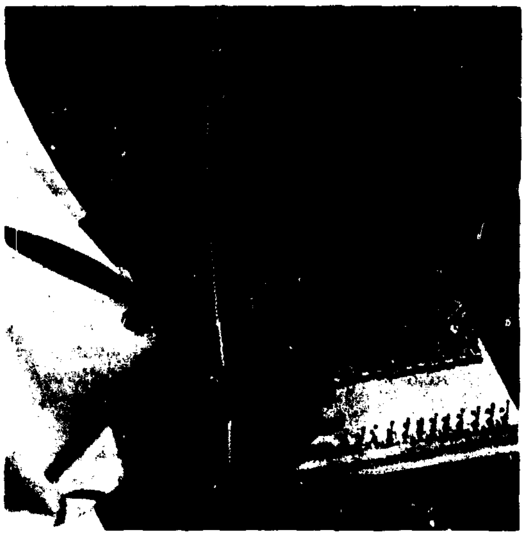
SUMMARY OF REGIONAL CHARACTERISTICS

	Nicaragua-Costa Rica Border Region	Panamanian Isthmus	Darien Isthmus	Atrato-Truando Region
Width:	125-170 miles.	30-60 miles.	50-80 miles.	90-110 miles.
Terrain:	The lowest pass on the Continental Divide is at about elevation 150 feet. Lake Nicaragua, 100 miles long and 45 miles wide, averages 105 feet. Mountain ranges east of the lake are broken by passes at about 400 feet and the San Juan Valley at about 120 feet. Dense jungle exists throughout except for cleared areas near the lake and in the vicinity of the divide.	The lowest pass on the Continental Divide is at about elevation 300 feet. Gatun Lake on the Atlantic side of the divide averages 85 feet. Jungle growth covers inland areas; the rolling hills in coastal areas are partially cleared.	The lowest suitable pass in the divide is at about elevation 1,000 feet. The Continental Divide lies about 10 miles south of the Atlantic coast. The centrally located Chucunaque Valley runs in a southeasterly direction to join the Tuira Valley. The Pacific Hills at average elevation of 1,000 feet and the Gulf of San Miguel are the principal features of the west coast. There is heavy tropical jungle throughout.	Passes exist through the divide at elevations of about 1,000 feet (about 450 feet on Route 23). The Atrato Valley swamp is the most significant feature with elevations from sea level to 10 feet. The Continental Divide forms the western boundary of the region as it cuts across the isthmus. Its 20-mile width separates the Atrato Valley from the Pacific Ocean. Thick tropical jungle or lush marshland cover the region.
Geology:	Mainly volcanic tuff; assumed favorable for canal construction; subsurface geology is not well known.	Varies from weak shales and sandstones to hard basalt and agglomerates.	Pyroclastic and volcanic rocks of basaltic composition, sedimentary rocks and weak shales.	Varies from unconsolidated sediments to sedimentary rocks and competent volcanic rocks.
Tide range (avg/peak)	Pacific 6.2 ft/9.7 ft; Atlantic 0.7 ft/2.6 ft.	Pacific 12.7 ft/ 21.7 ft; Atlantic 0.7 ft/2.6 ft.	Pacific 14.3 ft/ 23.0 ft; Atlantic 1.0 ft/2.7 ft.	Pacific 8.4 ft/14.0 ft; Atlantic 1.1 ft/2.9 ft.
Coasts:	Pacific deep water available within 1/2 mile, and protected harbor sites exist. Atlantic deep water is as far as 3 miles offshore with no good natural harbor sites available.	Deep water is close in on the Atlantic side, 15 miles out on the Pacific side. The Atlantic side offers little natural protection, the Pacific offers fair protection.	The Pacific has deep water within 1/2 mile and the Gulf of San Miguel provides a large natural anchorage site. The Atlantic side 10-fathom contour is 2 miles offshore. Offshore islands provide limited protection.	The Pacific has deep water within 1½ miles and some natural protection. The Atlantic side 10-fathom contour is 2 miles offshore. The Gulf of Uraba, Candelaria Bay and Colombia Bay provide fair to good protection.

TABLE 4-3

SUMMARY OF REGIONAL CHARACTERISTICS (Cont'd)

	Nicaragua-Costa Rica Border Region	Panamanian Isthmus	Darien Isthmus	Atrato-Truando Region
Harbors:	Nearest Pacific coast ports are Corinto and Punterenas. On the Atlantic shallow draft harbors exist at Bluefields and Puerto Limon. All are more than 80 miles from prospective routes.	Best of areas considered. The Canal Zone has excellent port facilities available at both ends of the canal for ships with drafts up to 40 feet.	No harbors exist on the Atlantic coast. On the Pacific coast La Palma provides minimum port facilities for shallow draft vessels with room for expansion.	Colombian port of Turbo on the Atlantic coast has a depth of 12 feet with 10-foot depths available along harbor piers. No harbors exist on the Pacific coast, although Humboldt Bay affords some natural protection
Communications:	San Juan River and Lake Nicaragua allow water access to the interior. No transisthmian highway or railroad exists. The Pan American Highway crosses the area within 10 miles of the Pacific coast. There is no road along the Atlantic coast or all-weather airfield.	The existing canal and Gatun Lake offer easy water access to the region. A transisthmian railroad and a two-lane all-weather highway exist. All-weather roads generally parallel both coasts. Jet airfields exist.	The Chucunaque and the Tuira Rivers allow access to the interior in small boats. No roads, railroads, or all-weather airfields exist. Pan American Highway survey has been in progress for several years.	The Atrato River provides excellent access for shallow draft vessels. No railroads or all-weather weather airfields exist. Pan American Highway survey has been in progress for several years.
Labor supply:	Labor may be available from the Nicaraguan m metropolitan region across Lake Nicaragua; also from Costa Rica and Nicaragua along Pan American Highway. Local inhabitants are unskilled.	Sources exist in centers of population of the area. The number of inhabitants skilled in heavy construction is limited.	Labor is not readily available. The area is remote from major population areas. Local inhabitants are unskilled.	Labor is not readily available. The area is undeveloped. Local inhabitants are unskilled.
Rainfall average:	Atlantic side 250"; Pacific side 60".	Atlantic side 130"; Pacific side 70".	Atlantic side 100"; Pacific side 80".	Atlantic side 80"; Pacific side 200".
Local development:	Subsistence farming, lumbering, fishing and ranching.	Farming and ranching, light industry and commerce.	Subsistence farming, lumbering, ranching, and fishing.	Selective lumbering and subsistence farming.



A technician examines a box of specimens for identification.

Technicians identify insects for possible disease carrying capabilities.

A technician examines an animal for possible disease.

Animal collectors with some of the specimens they collected for examination.

The study required the identification of all possible sources and avenues of transmission of human disease in the areas under consideration. To accomplish this thousands of specimens were collected and examined to determine if they could act as reservoirs or vectors of human diseases.

CHAPTER 5

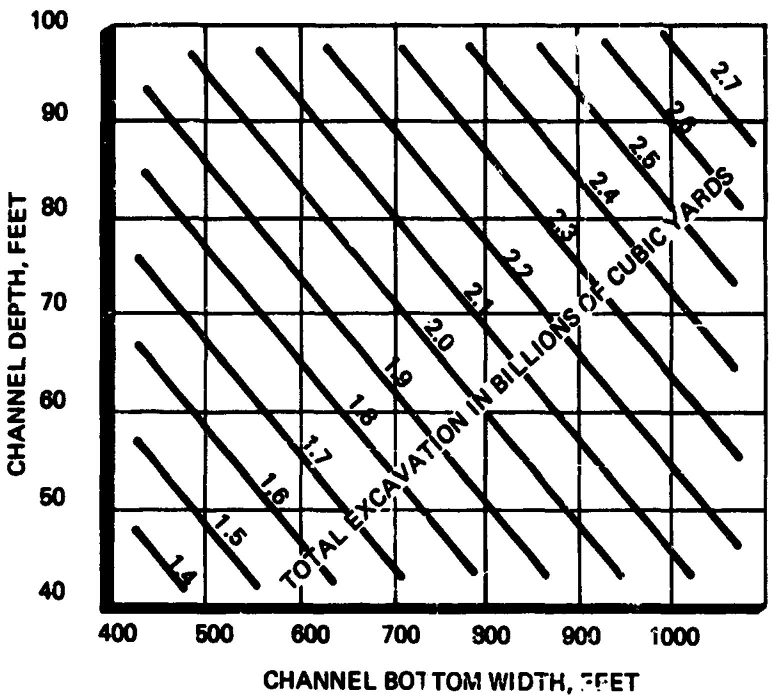
CONVENTIONAL EXCAVATION TECHNOLOGY

Nearly three-quarters of the cost of constructing a sea-level canal by conventional means is associated with excavation. Therefore, wherever conventional excavating techniques might be employed, particular attention has been given to alining routes so as to minimize the volume of excavated material.

The present lock canal in Panama stands as a monument to the ingenuity and organizational skill of American earthmovers. They succeeded on a grand scale where others had failed. The magnitude of their achievement can be realized by comparing it with other large excavation works, as shown below:

Project/Dates[22,23]	Cubic yards excavated	Significant dimensions
Suez Canal; 1859-1870	97,000,000	100 miles long; 150 ft wide by 26 ft deep; surface elevations up to 100 feet.
French Canal, Panama; 1881-1898	78,000,000	48 miles long; 75 ft wide by 30 ft deep; surface elevations up to 112 feet; excavation 70% completed when abandoned.
Panama Canal; 1904-1914	2[illegible]0,000	48 miles long; 300 ft wide by 42 ft deep; surface elevations up to 155 feet.
Panama Canal; 1915-1970	190,000,000	About 150 million cubic yards of maintenance dredging and about 40 million cubic yards removed in widening Gaillard Cut to 500 feet.
Mahoning Iron Mine, Hibbing, Minn.; 1895-present	700,000,000	3.3 miles by 0.7 miles; maximum depth 535 feet.
Kennecott Copper Mine, Bingham, Utah; 1904-present	1,000,000,000	Two mile diameter; maximum depth 1700 feet.
Morenci Copper Mine, Morenci, Ariz.; 1937-present	500,000,000	1.5 mile diameter; maximum depth 700 feet.

The construction of an isthmian sea-level canal would require an effort surpassing all previous projects in both extent and rate of excavation. At the very least, it would involve the removal of nearly 1.5 billion cubic yards of material. Larger channels would require the excavation of even greater quantities, as shown in Figure 5-1.



Approximate excavation quantities on the Route 10 alinement for various channel dimensions.

FIGURE 5-1.

Excavation systems: Many of the techniques and much of the equipment available for this work today were developed during construction of the Panama Canal. In the intervening years, capabilities have been increased and adapted to specific needs of the coal, iron, and copper mining industries, as well as those of large public works projects. In the same period, substantial improvements have been made in hydraulic dredges, while whole new families of tracked and wheeled vehicles have entered the field of earth moving.

Good construction practice requires a balanced system for excavating, hauling, and disposing of spoil. Hauling would be the critical factor in building a canal since, in general, the capacities of available haul equipment are less than those of large excavating machinery. Consequently, a balanced excavation system might contain excavation equipment smaller than the largest available. Thus, although 180-cubic yard shovels exist today, only those with 15 to 25 cubic yards capacity would be used for land-based canal excavation because

they are best suited to the largest trucks and rail gondolas now in use. In a water-based operation, however, barge-mounted stripping shovels of about 140 cubic yards capacity could be used efficiently to fill the large (3,000 cubic yard) scows that would carry away the spoil.

By far the greatest volumes of material excavated for a sea-level canal would be removed from the Continental Divide reaches. Three general systems might be employed in this work:

- Shovel excavation with truck haul;
- Open-pit mining with rail haul; and,
- Dipper dredge excavation with scow haul.

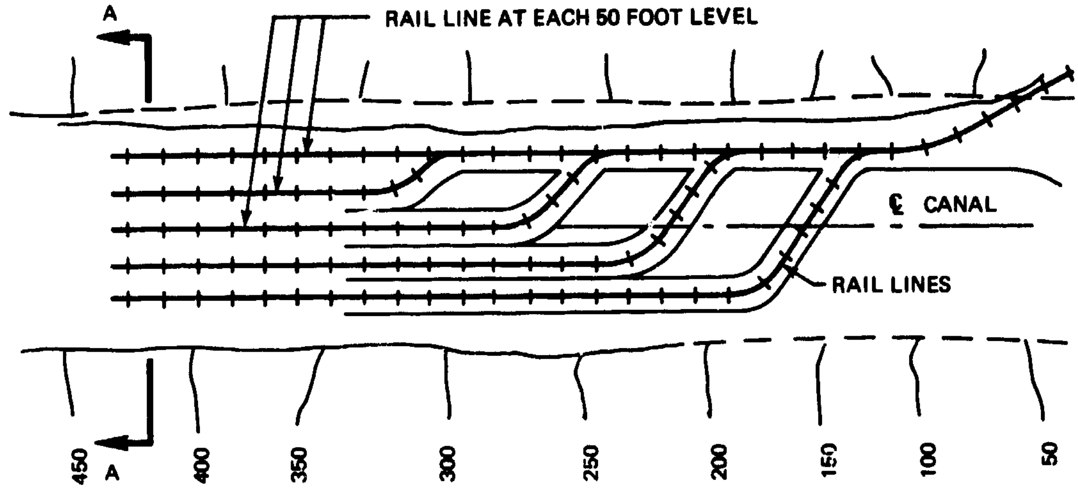
The first of these systems would use 15- to 25-cubic yard shovels and 100-ton dump trucks for reducing isolated high points to elevations where either of the other systems normally would be employed. The dump trucks, with their high mobility and ability to traverse steep grades, could handle relatively small work packages effectively, making it possible to operate several sites concurrently without significant increases in cost. They would have an economic haul range of about 3 miles; however, when loaded they would subject roads and bridges to severe stresses. Haul roads with 2-foot thick wearing surfaces of hard rock would have to be built and maintained continuously to withstand the adverse climatic conditions of the region.

The second system, open-pit mining with rail haul, would employ 15- to 25-cubic yard shovels to fill 110-ton gondolas in 20-car trains. Rail haul would be more economical than truck haul for moving large volumes of excavated material over relatively long distances. Recent innovations in rail equipment, such as remote-control trains with small crews and fast-acting automatic rotary car unloaders, make rail haul even more attractive under such conditions. Figure 5-2 shows schematically how the open-pit mining/rail haul concept might be applied to the construction of a canal. This system would be economical where haul distances are greater than 2 miles and adverse grades for loaded gondolas do not exceed 3 percent. Large volumes would have to be moved to offset the high cost of railbed preparation and laying track. Criteria for track layout would constrain the location and configuration of spoil areas.

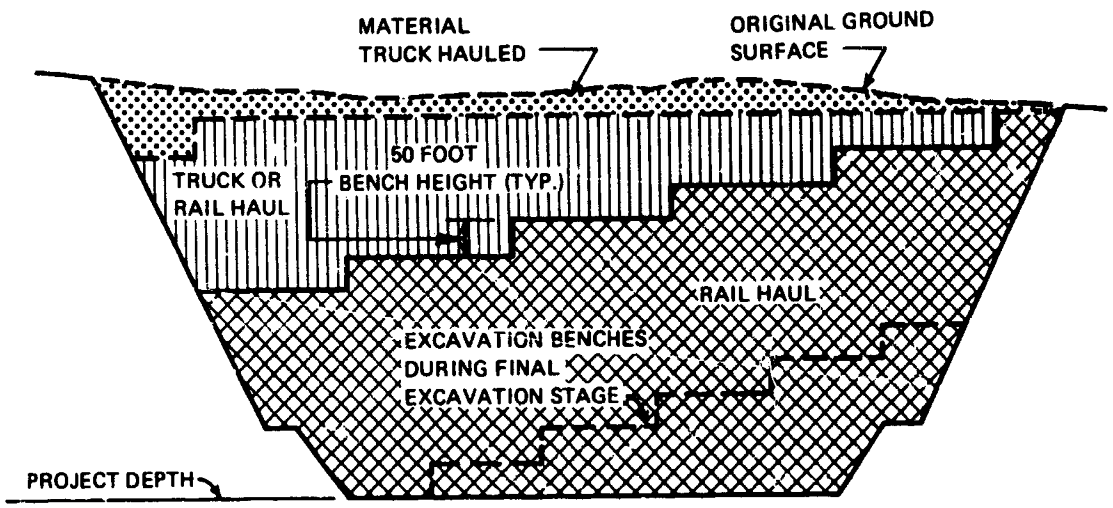
The third excavation system would use large, barge-mounted shovels loading into bottom-dump scows, each of which would hold as much material as an entire train of railroad gondolas. This system, being completely waterborne, could operate from existing lake or ocean levels, provided there is adequate depth for flotation in the excavation, haul, and disposal areas. It could be extended on a limited basis to dry land excavation. To the extent of its capabilities, it would provide the least expensive means of excavation. Its economy might be offset by adverse effects of dumping large amounts of material into marine environments. In unsheltered areas, high seas might force an occasional halt to operations.

All three systems would incorporate draglines as well as shovels, to be used in excavating material well below the equipment's level. In areas requiring wet excavation, draglines could be mounted on barges.

Mud, silt, sand, gravel, and soft rock would be removed from sheltered approach channels and low-lying reaches by hydraulic pipeline dredges. Their use would require that suitable disposal areas be available within pumping distance of the canal. A 2-mile limit



PLAN



SECTION A-A

TYPICAL BENCHING OPERATION

OPEN-PIT MINING/
RAIL HAUL CONCEPT

FIGURE 5-2

would be preferable, although booster pumps are capable of transporting spoil as far as 3 to 5 miles. Hydraulic dredges could be built to excavate material down to the maximum depths required to meet channel criteria.

Figure 5-3 shows how these excavation systems might be employed in crossing the Continental Divide on Route 14 Separate. Rail haul is maximized in this case. Estimates for this route are based upon the systems shown in the figure.

Figure 5-4 shows some items of currently available excavating and hauling equipment which might be employed to construct a sea-level canal, and Table 5-1 indicates how excavating and hauling equipment have been balanced for the estimates included in this study.

TABLE 5-1
CAPABILITIES OF EQUIPMENT SYSTEMS UNDER SEA-LEVEL CANAL CONDITIONS BASED ON THE OUTPUT OF A SINGLE EXCAVATOR

Major Excavating Equipment		Hauling Equipment Considered		
			Number of Units Per Excavator[c] Level Haul Distances	
Type	Single Unit Production Capacity Cu. Yd./Hr.	Type	2 miles	5 miles
Shovel, 15-cu. yd.	560-780[a]	100-ton dump trucks[b]	6	13
		110-ton rail cars	8	15
Shovel, 25-cu. yd.	610-1,210[a]	100-ton dump trucks[b]	9	18
		110-ton rail cars	11	20
Dipper dredge 35-cu. yd.	630-1,230[a]	3,000-cu. yd. scow	1.9	2.4
Dipper dredge 140-cu. yd.	2,400-5,000[a]	3,000-cu. yd. scow	3.8	5.8
Dragline (barge-mounted) 35-cu. yd.	420-1,000[a]	3,000-cu. yd. scow	1.7	2.1
Hydraulic dredge, 27"	1,000-2,000[d]	Booster pumps	1	3
Hydraulic dredge, 48"	2,400-5,000[d]	Booster pumps	1	3

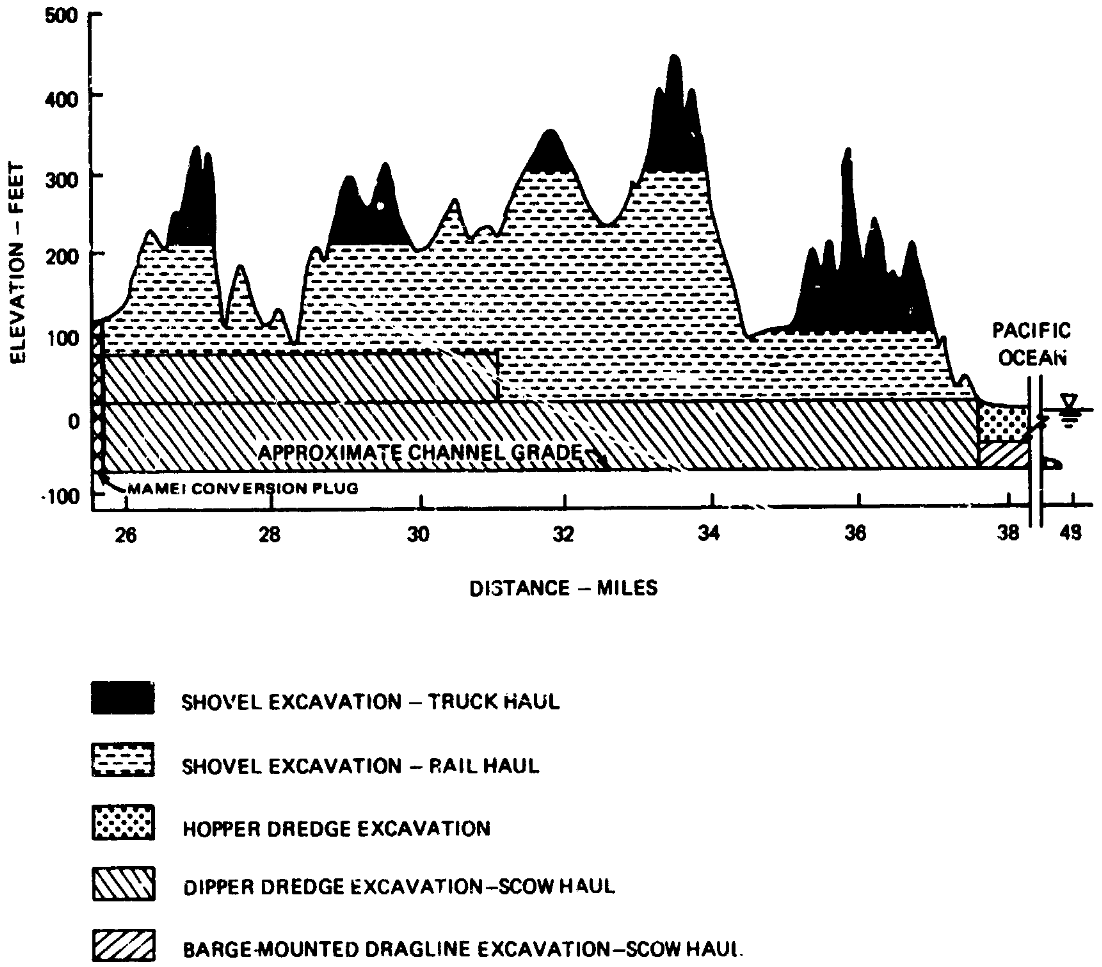
[a]Rates vary from hard rock to overburden.

[b]Experience with 200-ton dump trucks was considered insufficient for use in developing estimates for this study.

[c]The number of units would vary with the site conditions and the system layout. The combination of several excavators and haul units would appreciably affect loss time of the system and alter the number of units required per excavator.

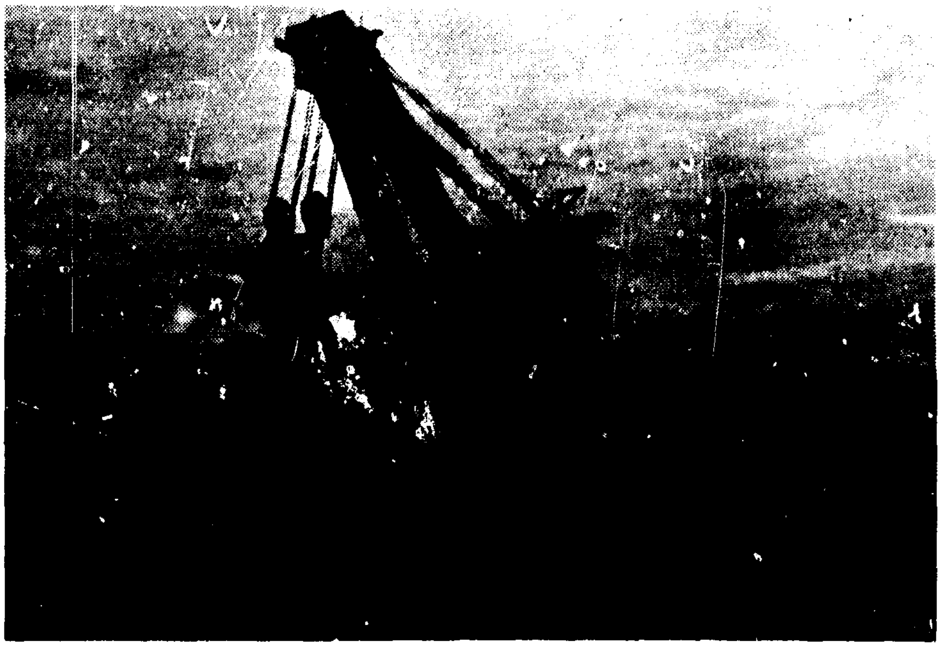
[d]Soft materials.

Drilling and blasting: The varied geology of the American Isthmus would make it necessary to use many different drilling and blasting techniques for breaking up material



PROFILE–DIVIDE REACH–ROUTE 14 SEPARATE

FIGURE 5-3

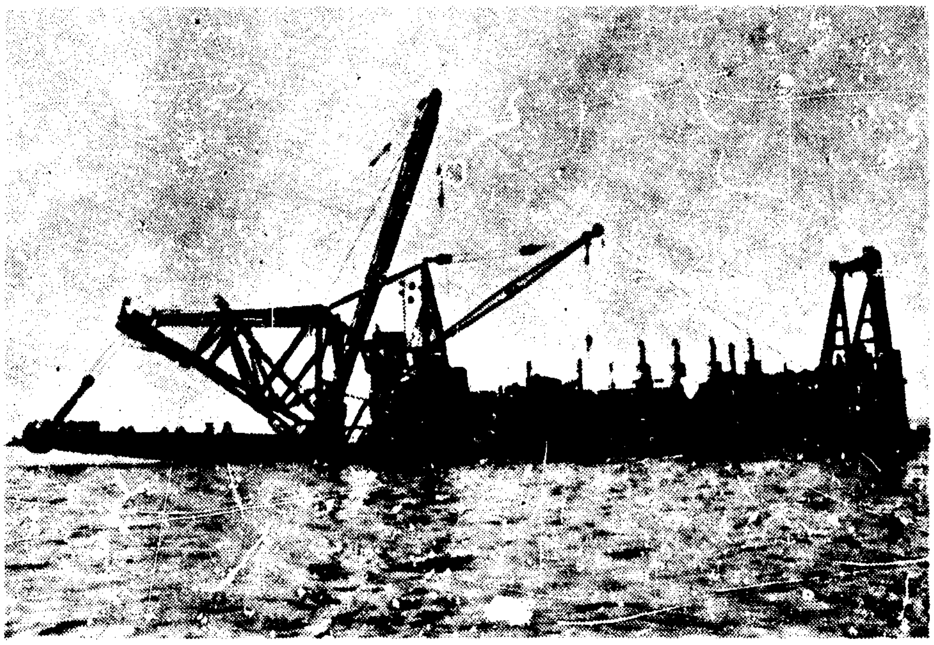


A 180-cubic-yard stripping shovel.

A 15-cubic-yard dragline

CONVENTIONAL EXCAVATION EQUIPMENT

FIGURE 5-4



A 27-inch hydraulic cutterhead pipeline dredge.

A 15 cubic-yard dipper dredge.

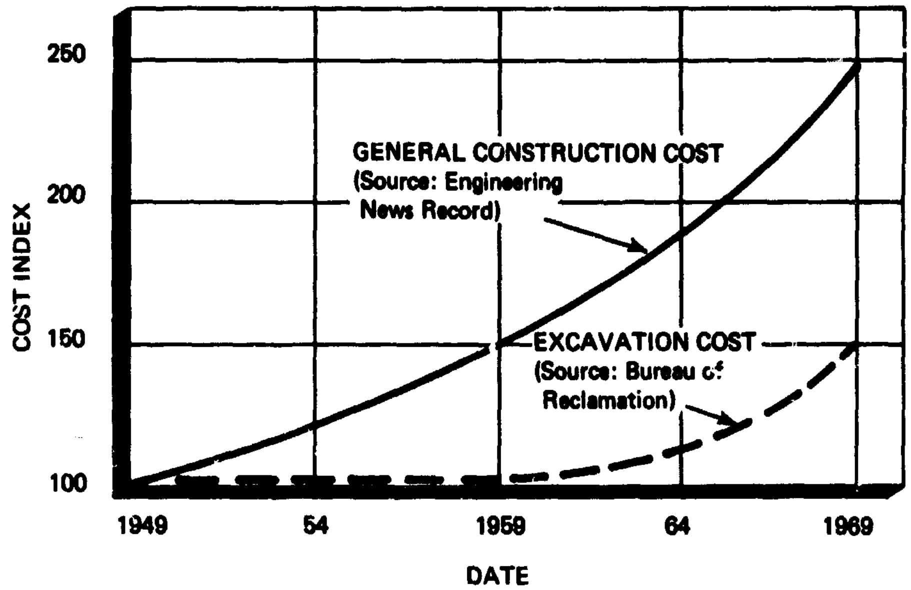
CONVENTIONAL EXCAVATION EQUIPMENT

FIGURE 5-4

A 15-cubic-yard front-end loader.

A 100-ton bottom-dump semi-trailer.

CONVENTIONAL EXCAVATION EQUIPMENT
FIGURE 5-4



Trends in general construction costs and excavation costs.

FIGURE 5-5.

prior to loading. The drills considered most suitable for this project are self-propelled rotary drills, track-mounted for dry excavation and barge-mounted for wet excavation. Explosives that would be appropriate for the conventional canal project fall into three general categories: dynamite, ammonium nitrate-fuel oil, and slurries. Of these, ammonium nitrate-fuel oil was used for estimates in most cases because of its low cost and relative insensitivity.

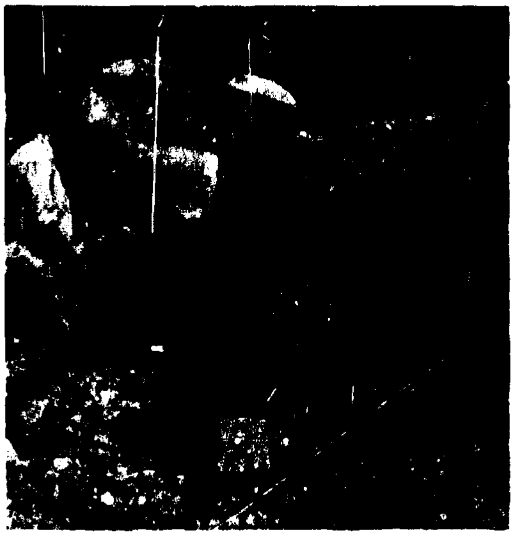
Disposal methods: A portion of the excavated material would be used for embankments, dikes, dams, and flood control levees. Selected material would also be utilized for railroad ballast, haul road surfacing, and bank protection. The majority of the spoil, however would not be used for construction, but would be placed in valleys along the alinement. Ocean areas would be used where practicable. On Routes 10, 14, and 15, parts of Gatun Lake would be used for disposal. Despite the general adequacy of spoil areas, environmental considerations dictate that they be carefully selected. This is discussed more fully in Chapter 10.

Excavation cost trends: Historically, unit costs of excavation have not risen as fast as costs in the construction industry as a whole. The reasons for this are twofold:

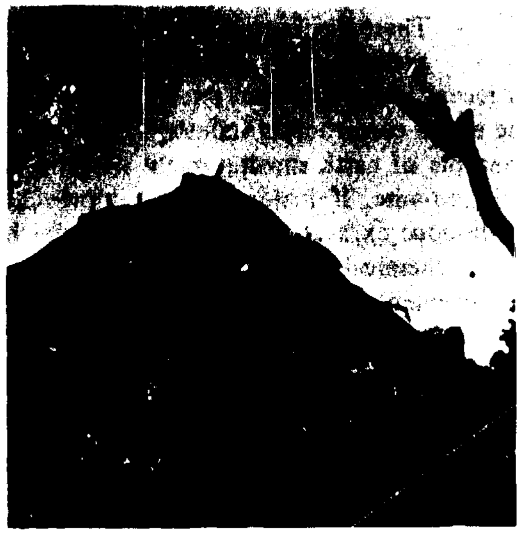
– The principal cause of increases in construction costs is the constantly rising cost of labor. (Large scale excavation is less labor-intensive than the remainder of the industry; hence, it is less sensitive to changes in labor costs.)

- There has been steady improvement in the efficiency of excavating machinery and systems.

In recent years, however, excavation costs have begun to rise at a rate approaching that of the entire construction industry. (See Figure 5-5.) As excavation technology improves, new concepts of earth moving might offer means of reducing costs. Methods which appear to hold promise, if major product improvements can be achieved, include conveyor belts, continuous excavators, monitors and sluicing, nuclear-powered dredges and excavation by either chemical or nuclear explosives. There is no doubt that some or all of these improvements will be made. However, since their application lies in the future and their full extent cannot be foreseen, conventional excavation estimates in this study are based on the use of existing equipment and proven methods for which reliable costs factors are available.



Choco Indians gather to inspect a helicopter that landed near their village. Helicopter was delivering supplies to one of the hydrology stations.



Native labor was utilized in the construction of work camps along the routes. This bohio is similar to most huts constructed for these camps.

U.S. Army medical teams also furnished medical attention to the local natives whenever they visited the work camps.

Natives aided in the collection of animal specimens such this. Specimens were studied as possible reservoirs or vectors of human disease.

The local inhabitants of the areas investigated were very curious about the personnel of the survey parties and their equipment.

CHAPTER 6

NUCLEAR EXCAVATION TECHNOLOGY

The economies that may be realized from applying nuclear excavation techniques to the construction of a sea-level canal stem from three sources:

- The force of the explosion not only fractures material but moves it out of the cut.
- Economies of scale are inherent in large nuclear explosions–the higher the yield, the lower the unit cost of energy produced.
- Nuclear explosives are small and compact compared to chemical explosives of comparable yields; they can be emplaced quickly and cheaply.

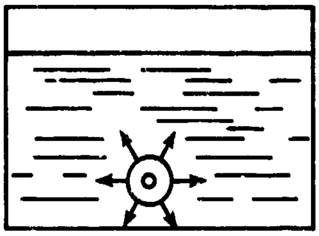
Such potential advantages make nuclear explosives an attractive means for constructing deep cuts that would be prohibitively expensive if excavated conventionally. Associated with these economies, however, are certain effects which must be assessed fully before any decision to adopt nuclear excavation techniques is made. For this assessment, an understanding of the nuclear cratering process and its effects is essential.

The nuclear cratering process: (Figure 6-1.) A nuclear explosion releases an extremely large amount of energy from a concentrated source in less than one-millionth of a second. This sudden release generates a shock wave which radiates from the point of explosion, transmitting energy to the surrounding material (Figure 6-1(a)). This energy is sufficient to vaporize everything in the immediate vicinity of the explosion. As the shock wave expands beyond the vaporized region, its intensity diminishes. It creates successive zones of melted, crushed, and fractured rock, beyond which only elastic deformations occur. When the shock wave reaches the ground surface (Figure 6-1(b)), a tensile wave is reflected, which causes spalling at the surface and fractures the underlying rock as it travels downward (Figure 6-1(c)).

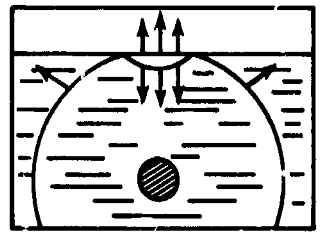
Generation of the shock wave is followed immediately by the expansion of a cavity containing vaporized rock and other gaseous products of the explosion. The cavity grows spherically until it meets the downward-moving tensile wave which relieves the stresses on its upper surfaces. This causes the cavity to expand preferentially toward the ground surface, further accelerating the material already set in motion by the shock wave.

As the cavity continues to expand upwards, the ground surface above begins to rise. A mound forms (Figure 6-1(d)) and grows until it breaks up (Figure 6-1(e)) and the underlying material, accelerated by expanding gases, is thrown upward and outward in ballistic trajectory. Some of this material (fallback) drops into the cavity, while the remainder (ejecta) falls outside (Figures 6-1(f) and 6-1(g)).

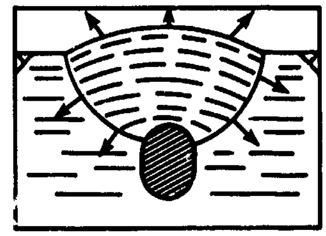
Nuclear crater properties: (Figure 6-2.) The true crater produced by the explosion is partially filled by fallback. This material varies in size and forms concave slopes, producing



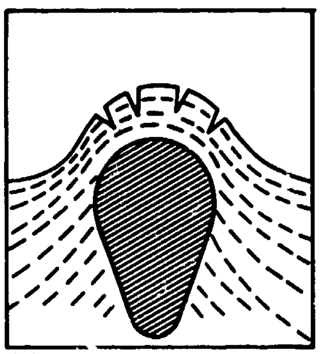
(a) The explosive detonates, generating a shock wave which vaporizes and melts the immediately surrounding material.



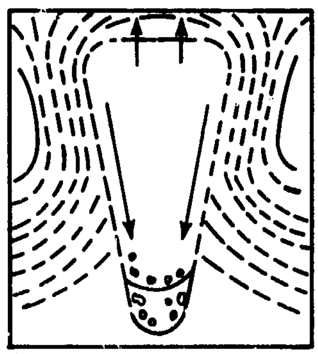
(b) The shock wave reaches and is reflected from the surface, causing it to spall, as the cavity grows spherically.



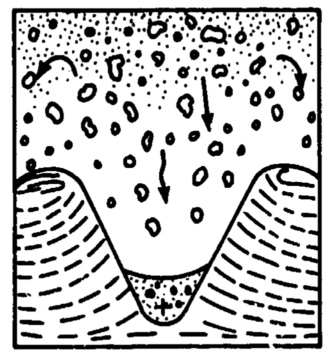
(c) The reflected tensile wave reaches the cavity, causing accelerated growth toward the surface.



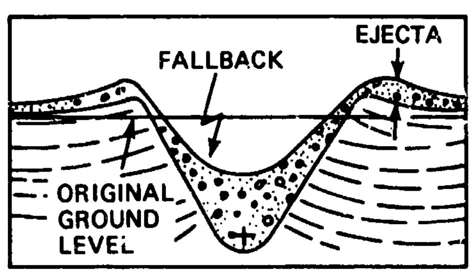
(d) A mound grows and then begins to dissociate, allowing vapor to filter through the broken material.



(e) The mound reaches its maximum development as major venting occurs; crater sides begin to slump.



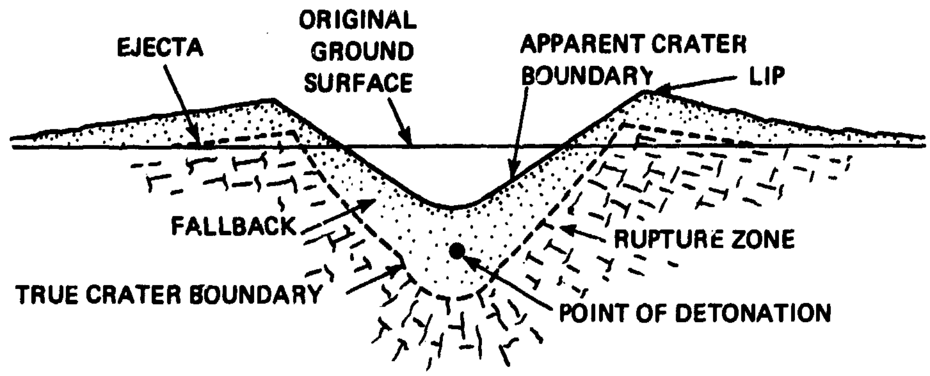
(f) The mound completely dissociates into fallback and ejecta, which are deposited to form the apparent crater and its lip.



(g) Final configuration of a typical row charge excavation.

NUCLEAR CRATER FORMATION

FIGURE 6-1



Apparent Crater - That portion of the visible crater which is below the original ground surface.

True Crater - The entire void initially created by the explosion including both the apparent crater and the broken and disarranged fallback material.

Fallback - Material thrown into the air by the explosion, which does not have sufficient horizontal velocity to escape the crater area and thus falls back into the void initially created by the explosion (true crater).

Ejecta - Material thrown into the air by the explosion with sufficient horizontal velocity to escape the crater area. Ejecta landing just outside the void created by the explosion forms part of the crater lip.

Rupture Zone - The region bounding the true crater in which material has been sufficiently stressed to cause fracturing, crushing, and some slight local displacement.

CROSS SECTION OF A ROW CRATER

FIGURE 6-2

an excavation called the apparent crater which is approximately hyperbolic in cross section.* The average slope angle of the fallback, measured from the horizontal, ranges between 25 and 40 degrees depending upon the type of material. Because of the dynamic manner in which it has been deposited, this material stands at a slope angle somewhat flatter than its natural angle of repose. The crater lip is formed by uplifting of the ground surface adjacent to the crater and by deposition of ejecta.

In excavating a canal, a number of explosives buried in a row would be detonated to produce a row crater. In a row crater the height of the side lips above the original ground surface is about two-thirds the depth of the apparent crater. The lips slope gradually to the undisturbed ground as they extend outward.

The dimensions of a row crater depend on the type of material being excavated and its moisture content, the yield and burial depth of the explosives, and their spacing within the row. Navigation channels are usually considered to be rectangular in cross section; the cross section of a nuclear crater is hyperbolic. Therefore, to produce a channel having at least the required rectangular dimensions, a nuclear explosion must create an oversized excavation. Figure 6-3a shows a conventionally dug channel through a surface elevation of about 300 feet. Figure 6-3b shows a nuclear-excavated channel through an elevation of approximately 1,000 feet. A major advantage of the large nuclear channel would lie in its ability to accommodate sedimentation or surficial slope adjustments without restricting navigation or requiring remedial excavation. Equally important, its great depth would make it relatively invulnerable to traffic interruptions caused by disabled ships.

The simultaneous detonation of a row of explosives produces a linear crater with a larger cross section than a single crater produced by any one of the explosives. This enlargement occurs because the explosives effects of adjacent charges interact to impart greater energy to the surrounding material. Thus, a larger true crater is formed and the broken material is thrown farther. The resulting increase in crater dimensions is called enhancement. Enhancement factors used in this study range from 1 to 1.25.

As the required width and depth of the cut become greater, larger yields would be employed but the number of explosives would diminish. Since the cost of nuclear excavation is far more sensitive to number than to size of explosives, cuts with large cross sections would cost little more than small ones. Safety considerations, however, normally would dictate that the explosives used should be no larger than necessary to excavate the required cut.

Canal excavation concept: From an operational viewpoint, the simplest method of accomplishing nuclear excavation would be to detonate all explosives simultaneously, thus opening the entire nuclear channel at one time. However, the enormous amount of energy released by such a procedure would create unacceptable levels of airblast and ground motion for hundreds of miles from the canal alinement. To avoid this, the design concept calls for dividing the nuclear portion of the alinement into short sections excavated by separate detonations of several explosives in a row. The length of each row crater would be chosen to insure that ground motion and airblast would be within acceptable, conservatively selected

*Except where noted, the discussion refers to a crater formed by an explosive detonated at its optimum depth of burst, the depth that produces the apparent crater having the maximum volume attainable for the yield of explosive used.

FIGURE 6-3a

Ship passing through a single-lane conventionally dug canal, showing the navigation prism. (Maximum ground elevation shown is 300 feet. The navigation prism is 550 by 75 feet)

FIGURE 6-3b

Ship passing through a two-lane canal excavated by nuclear means, showing the navigation prism. (Maximum ground elevation shown is 1000 feet. The navigation prism is 1000 by 75 feet)

limits. The complete sequence of detonations would excavate a series of interconnected row craters to form the desired channel. The schedule would call for sequential excavation of alternate, rather than adjoining, sections to avoid the collapse by ground shock of immediately adjacent explosive emplacement holes and damage to explosives pre-emplaced for succeeding detonations. Thus, the channel would be excavated by two passes of detonations, each pass comprising a series of alternate sections of the channel. First pass operations would include drilling the pre-selected emplacement holes, loading the explosives and firing. This would take several months and would result in excavation of alternate sections of the channel amounting to about half of the total channel length. After a short delay for decay of radioactivity in the immediate area, identical operations for the second pass would be performed. Second pass detonations would remove the alternate sections left unexcavated by the first pass, providing a continuous channel. The row crater connections would not be completely smooth and some fallback material might even impinge on the required navigation channel. This material could be removed by barge-mounted draglines and bottom dump scows for disposal in nearby sections where the excavation provided considerable channel overdepth. Cost totals in this study include estimates for this remedial work.

The two-pass excavation concept described above provides a method for safe and efficient execution of channel excavation while keeping undesirable side effects to acceptable levels. Figures 6-4a and 6-4b show a channel at Fort Peck, Montana, formed by sequential detonations of three interconnected rows of high explosives in an experiment demonstrating the feasibility of creating a navigation channel by explosive means

Associated effects of nuclear explosions: Nuclear cratering explosions produce three unwanted effects: ground motion, airblast and radioactivity. Ground motion and airblast are common to all explosions; however, the great quantities of released energy in large nuclear explosions make their effects potentially hazardous over long distances. Radioactivity is unique to nuclear explosions and requires strict controls to avoid hazards and to alleviate psychological and sociological concerns.

The close-in hazards presented by these effects can be avoided by evacuating the inhabitants of affected areas. In the present study, the distances to which possibly harmful levels of ground motion, airblast, and radioactivity would extend were estimated for each detonation. These estimates were used to delineate the boundaries of areas that should be evacuated. The lateral (crosswind) limits of exclusion areas would extend 30 to 50 miles from the nearest detonation. Downwind they would extend to the coast, and that part of the ocean included in their extension would have to be kept clear of ships on detonation days.

At any given point the magnitude of ground motion and its effects depend on the yield of the explosive, its depth of burst, the materials through which the seismic pulse travels and the distance of the point from the explosion. In those cases where subsurface geologic conditions are known, the magnitude of ground motion can be predicted with a fair degree of confidence. Predictions of resultant effects, however, are more difficult because the response of structures cannot readily be determined. This is particularly true in areas where there are no building codes, where codes have not been strictly enforced, or where structures have undergone differential settlement or have deteriorated. Therefore, buildings that might be damaged would be evacuated to prevent personal injury. In a few cities

FIGURE 6-4a

Channel at Fort Peck Reservior, Montana, created in an experiment demonstrating the feasibility of creating a navigation channel by explosive means. This channel was excavated with 18 chemical explosive charges ranging from 5 to 40 tons. It is 1,300 feet long, 130 feet wide, and has an average depth of 17 feet.

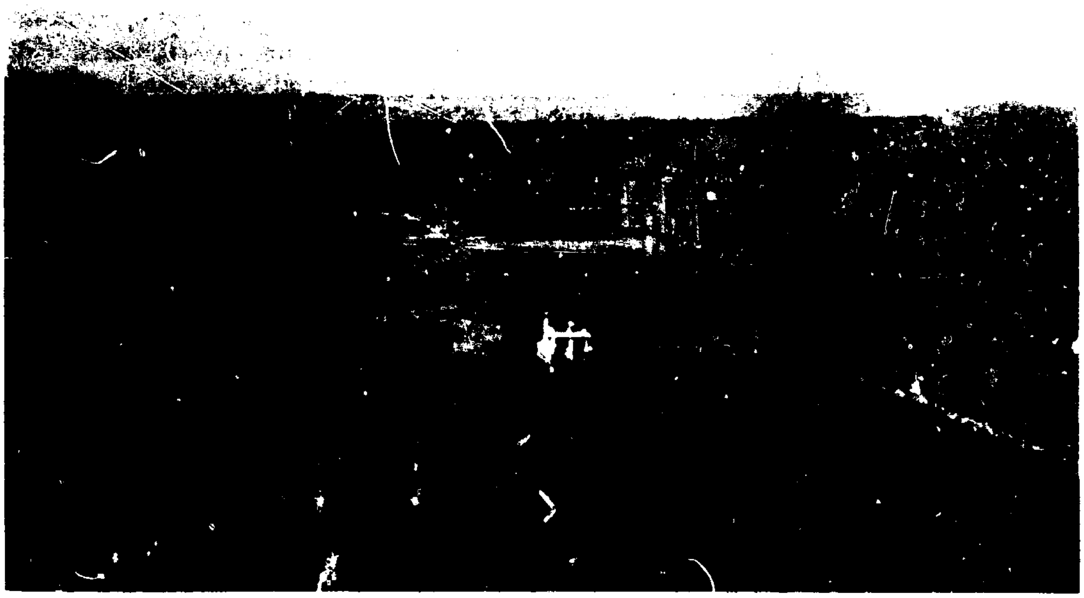


FIGURE 6-4b

Tugboat in Fort Peck channel. (Tugboat length 47 feet; beam 11 feet, draft 5 feet 7 inches.)

outside the exclusion area, a small number of high-rise buildings might have to be evacuated on days of very high-yield detonations.

Airblast, another likely source of concern caused by nuclear explosions, consists of air pressure waves which, under certain high-altitude meteorological conditions, could be focused on locations as far as 300 miles from the point of detonation. In such cases the principal adverse effects would be window breakage and possible attendant personal injury. Long-range airblast damage can be prevented or minimized by scheduling detonations to coincide with favorable meteorological conditions. Injuries from close-in airblast can be avoided by evacuating the immediate area of detonation.

As is the case with ground shock and airblast, the production and dispersal of radioactivity from a nuclear explosion and its effects on the environment and on man are reasonably well understood. Nuclear cratering detonations release only small amounts of radioactivity which, like all radioactive material, continually decay. These materials are both concentrated and dispersed by natural processes, such as rainstorms, runoff and flow of water, and biological assimilation in food chains, increasing the difficulties of tracing released radioactive materials. Therefore, prior to any nuclear explosion, the surrounding area would have to be studied carefully to determine pathways through which radioactivity might reach man. Any unusual features of the environment affecting transport through these pathways would be identified and closely monitored for some time following detonations. Certain areas would have to be evacuated during construction to minimize the risk of exposing the population to levels of external radiation beyond appropriate guides. In addition, shipping would have to be excluded from limited seaward areas for periods of 24 to 48 hours following each detonation in order to avoid radioactive fallout.

The evacuated area beyond the crater lips probably could be reoccupied by permanent residents within a few months after the final nuclear detonation. Resettlement of the exclusion area would be contingent on the results of detailed and continuous radiological surveys made to assure that no one would be exposed to levels of internal or external radiation beyond allowable limits. Further, the evacuation area would continue to be monitored to keep track of the remaining radioactivity and its effect on the local ecology. Radioactivity would be concentrated most heavily in the craters, crater lips and ejecta, a factor which must be taken into consideration throughout project planning and provided for in nuclear safety operations during construction. By the time the canal is opened to traffic, however, radioactivity levels would be sufficiently low so that no special precautions would be required for ships passing through the canal.

Residual radioactivity would have some deleterious effects on plant and animal life. The amount of radioactivity released probably would not do irreparable harm to any species as a whole; however, a few individual plants and animals would be expected to suffer some radiation damage.

Development of cratering technology: The assessment of nuclear excavation feasibility in this report is based on current cratering technology which has been developed jointly by the Atomic Energy Commission and the Corps of Engineers. The objectives of their research and development program have been:

- To acquire knowledge of cratering mechanisms and the ability to predict crater dimensions;

- To minimize the radioactivity released by thermonuclear explosives;
- To predict and control the effects of radioactivity, airblast, and ground motion on man and the environment; and,
- To understand the engineering characteristics of nuclear craters.

In support of this joint effort, as a part of its Plowshare* program, the Atomic Energy Commission planned a series of experiments aimed at extending the knowledge of cratering phenomena which had been derived from a small number of nuclear weapons effects tests, nuclear cratering experiments, and from large-scale high explosive experiments. When the Atlantic-Pacific Interoceanic Canal Study Commission was established, the Atomic Energy Commission reoriented its proposed experimental program to emphasize those tests which would assist investigations of sea-level canal routes, while meeting the more general objectives of Plowshare. The nuclear cratering experiments which originally were intended to provide data for this joint program are listed in Table 6-1. Those experiments which have been performed, including those accomplished before the establishment of the Canal Study Commission, are summarized in Table 6-2. Several craters achieved by these experiments are shown in Figure 6-5.

TABLE 6-1

EXPERIMENTS CONSIDERED NECESSARY IN 1965 TO DETERMINE FEASIBILITY OF NUCLEAR EXCAVATION

Yield	Material	Type of Experiment	Purpose
About 10 kt	Hard rock	Point charge (single crater)	To provide datum point for scaling crater parameters and explosion effects.
About 100 kt	Hard rock	Point charge (single crater)	To provide datum point for scaling crater parameters and explosion effects.
About 1 kt per charge	Hard rock	Multiple point charges (row crater)	To verify concepts of row excavation in flat terrain as determined by chemical explosives.
1 to 10 kt per charge	Hard rock	Multiple point charges (row crater)	To verify row excavation design concepts through terrain with varying elevations.
About 10 to 100 kt per charge	Hard rock	Multiple point charges (row crater)	To execute a practical demonstration project which would incorporate the knowledge gained from the experimental program.

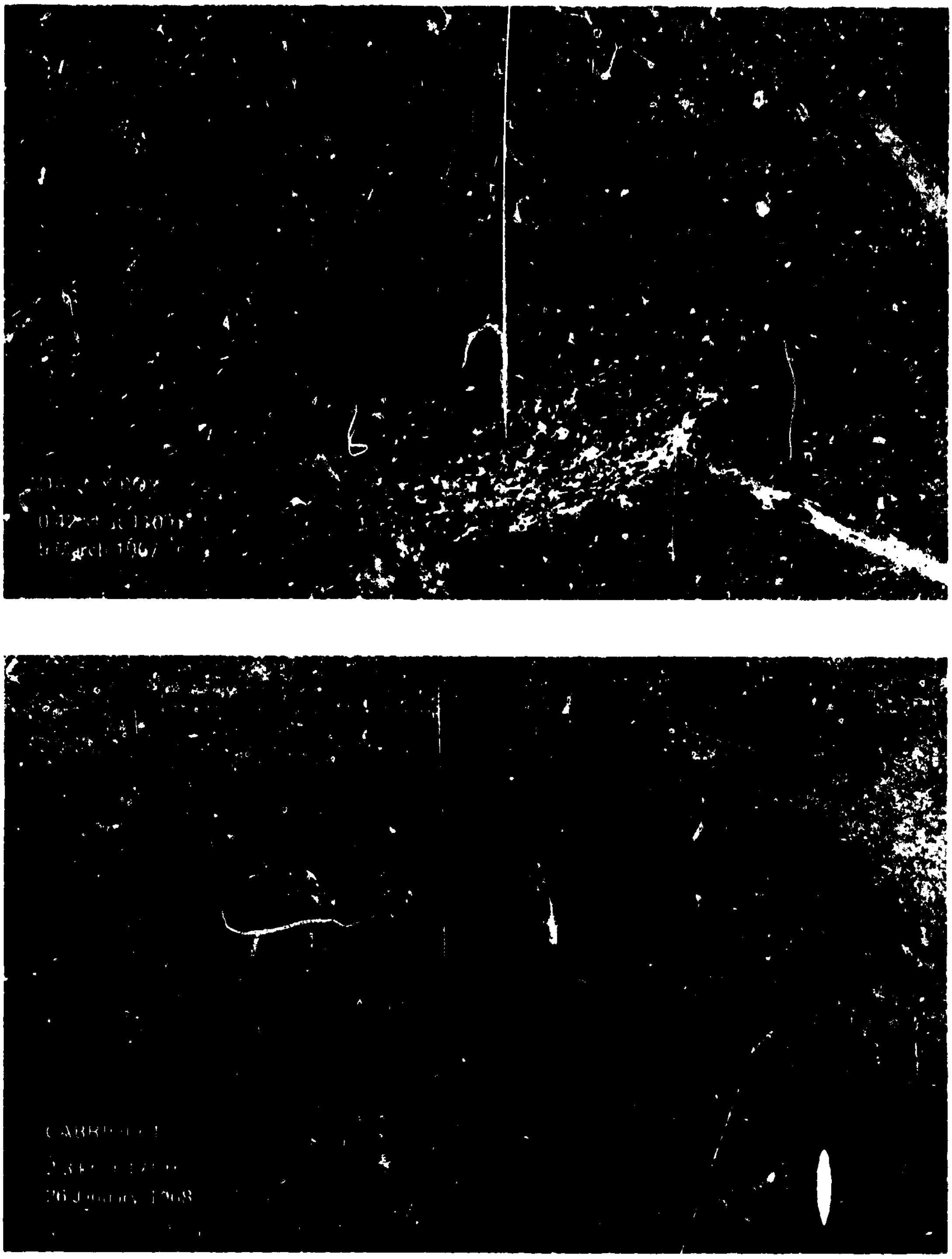
*The Atomic Energy Commission's program to develop the peaceful uses of nuclear explosives.

TABLE 6-2
COMPLETED NUCLEAR CRATERING EXPERIMENTS

Name/ Date/ Yield	Material/ Depth of Burst	Purpose	Results	Significance
Danny Boy Mar 1962 0.42 kt.	Basalt 110 ft	Determine cratering capabilities of nuclear explosives in hard, dry noncarbonate medium; determine amount, distribution and decay of radioactivity by a nuclear explosive detonated near optimum depth of burst in a hard rock medium.	Apparent crater radius: 107 ft. Apparent crater depth: 62 ft.	First nuclear crater in dry hard rock. Valuable information obtained on cratering mechanics.
Sedan Jul 1962 100 ft	Desert alluvium 635 ft.	Extend knowledge of cratering effect to the 100 kt range of yields; provide data on the general nature of the safety problems to be encountered by nuclear cratering detonations.	Apparent crater radius: 608 ft. Apparent crater depth: 323 ft. Nuclear explosions in the region of optimum depth of burst result in craters with radii about 10-20% smaller than equivalent-yield chemical explosives and with depths about the same.	First Plowshare nuclear cratering detonation.
Sulky Dec 1964 0.085 kt	Dry basalt 90 ft	Investigate the nature of the cratering curve at greater than optimum depth of burst; determine distribution of radioactivity; determine concentrations of certain radionuclides airborne at various distances; gain crater mechanics information at deeper than optimum depth of burst.	No crater; produced a mound of rubble.	Demonstrated that nuclear explosive effects cannot be scaled directly from chemical explosions. First nuclear cratering detonation under terms of the Limited Test Ban Treaty.
Palanquin Apr 1965 4.3 kt.	Rhyolite 280 ft.	Provide information on ability to reduce radioactivity released to atmosphere; determine the dispersion of radioactivity released; produce a mound for further study of quarry applications.	Apparent crater radius: 119 ft. Apparent crater depth: 79 ft. Inconclusive results due to stemming failure.	Predicted rubble mound but a crater developed as a consequence of stemming failure. Valuable information relating to stemming obtained.

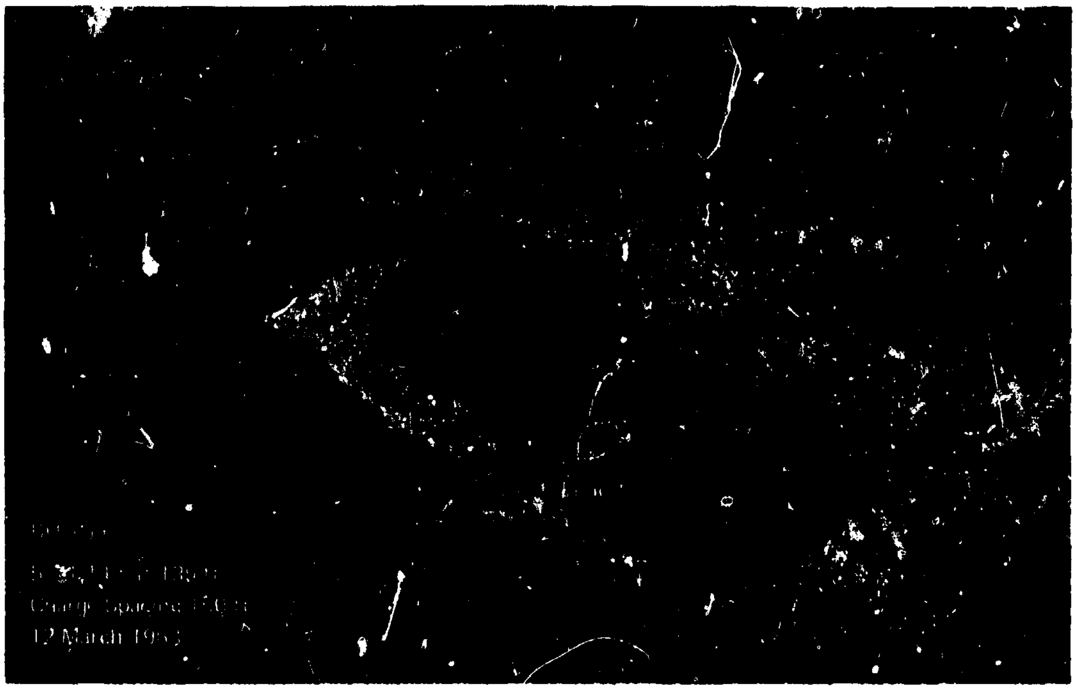
TABLE 5-2
COMPLETED NUCLEAR CRATERING EXPERIMENTS (Cont'd)

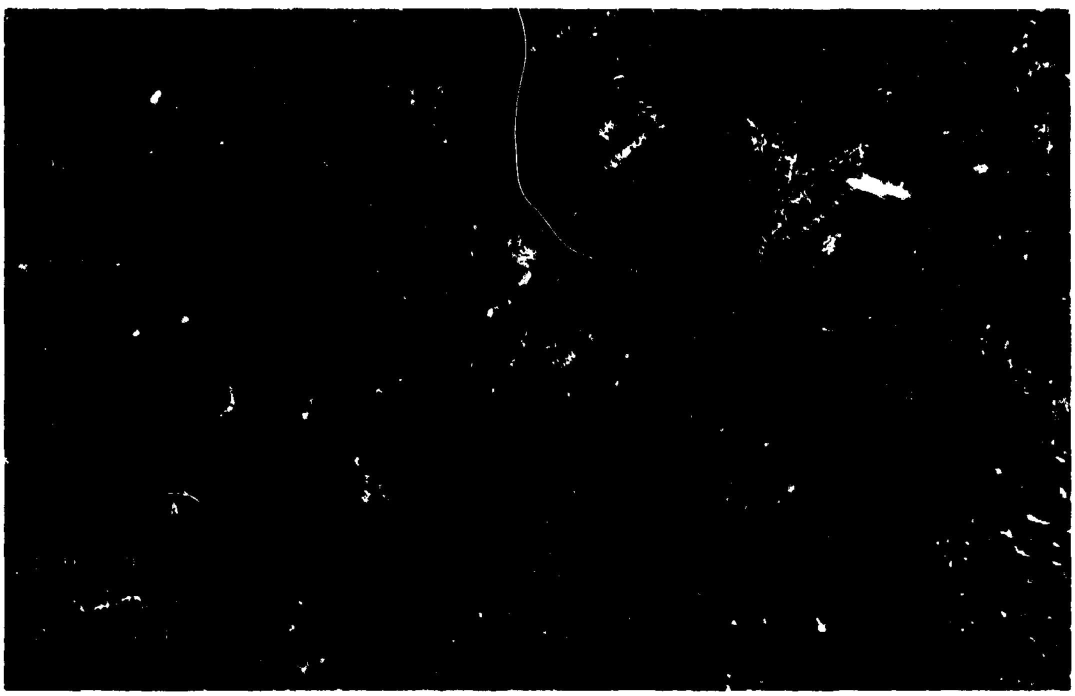
Name/ Date/ Yield	Material/ Depth of Burst	Purpose	Results	Significance
Cabriolet Jan 1968 2.3 kt	Dry layered rhyolite 170 ft.	Provide data on basic cratering effect from a nuclear explosion occurring at what appears to be the best depth in hard rock; verify recently developed computer codes and calculation techniques; study distribution of radioactivity.	Apparent crater radius: 179 ft. Apparent crater depth: 116 ft. Relatively small amount of radioactivity released.	First in series of excavation experiments to support Atlantic-Pacific Interoceanic Canal Study Commission. Scaled dimensions larger than Danny Boy obtained at a shallower depth of burst.
Buggy Mar 1968 5@ 1.1 kt	Multi-layered basalt 125 ft.	Obtain basic data on row cratering phenomenology through level terrain in a dry rock and on radioactivity release	Apparent crater width: 254 ft. Apparent crater depth: 60 ft. Apparent crater length: 857 ft.	Advanced the technical knowledge required for nuclear excavation of a sea-level canal. Confirmed basic concepts of channel excavation derived from high-explosive experiments at very low yields; supported value of theoretical cratering calculations in predicting effects of nuclear detonation in an untested environment.
Schooner Dec 1968 31 kt	Layered tuff 355 ft.	Examination of physical and chemical parameters which affect cratering at low intermediate yields.	Apparent crater radius: 426 ft. Apparent crater depth: 208 ft.	Extended hard rock nuclear cratering data collected from Cabriolet to that of a nuclear experiment of a higher yield.



REPRESENTATIVE NUCLEAR CRATERS OF THE PLOWSHARE EXCAVATION PROGRAM

FIGURE 6-5





REPRESENTATIVE NUCLEAR CRATERS OF THE PLOWSHARE EXCAVATION PROGRAM

FIGURE 6-5

The first objective of this program has been twofold: to understand the cratering mechanism and to predict its results. To date, both of these goals have been met only in part. The Atomic Energy Commission has developed a method for computing cratering phenomena in terms of basic laws of physics. This technique was used to predict the dimensions of the Schooner crater and the cratering characteristics of the complex basalt flows in which the Buggy experiment was performed. Applying the knowledge thus acquired, a better understanding of the Sedan experiment has been reached, including the effects caused by the moisture content of the cratered material. Because of its complexity, this analytical approach becomes more difficult to apply as yields increase. Calculations have been completed at the 1-megaton level, using the measured strength characteristics of rocks found along proposed nuclear excavated canal routes, and curves showing expected crater dimensions have been developed for the divide rock by calculating crater dimensions at several depths of burst. Computer calculations tend to predict crater dimensions in canal rock somewhat greater than those predicted by scaling up in yield from the nuclear craters produced to date. Nuclear excavation designs for this study rely mainly on scaled crater dimensions; this is considered the more conservative approach. Verification of the validity of these calculations can be obtained only by large-scale experiments.

Existing computer programs for cratering are two-dimensional and cannot be applied directly to row cratering experiments such as Buggy, which would require a three-dimensional program. The current understanding of the interaction between charges in a row needs to be refined by additional experiments. Chemical explosives are partially suitable for this purpose. Buggy demonstrated the feasibility of nuclear row charge excavation at low yields and established that relatively wide spacings can produce uniform channels free from severe irregularities, even in complex geologic formations. Still to be investigated with nuclear explosives are the concepts of row crater enhancement and techniques for connecting one row crater to another smoothly.

Verification is needed of the predictions underlying the nuclear excavation designs incorporated into this study. Such verification can be obtained only by large-scale tests in appropriate media. Cratering experiments considered necessary to verify current cratering theory are outlined in Table 6-3.

The second objective of the joint experimental program called for a reduction in the radioactivity released by nuclear excavation detonations. Considerable progress has been made toward achieving this objective through improved design of thermonuclear explosives to decrease fission products, special emplacement techniques and extensive neutron shielding.* Figure 6-6 indicates the degree of success achieved to date. Further substantial improvement is expected, which should result in a significant reduction in the size of exclusion areas shown in this study and in the number of people who would require evacuation.

*Neutron absorbing material is placed around the explosive to reduce the number of neutrons which might interact with the surrounding material to produce radioactive isotopes.

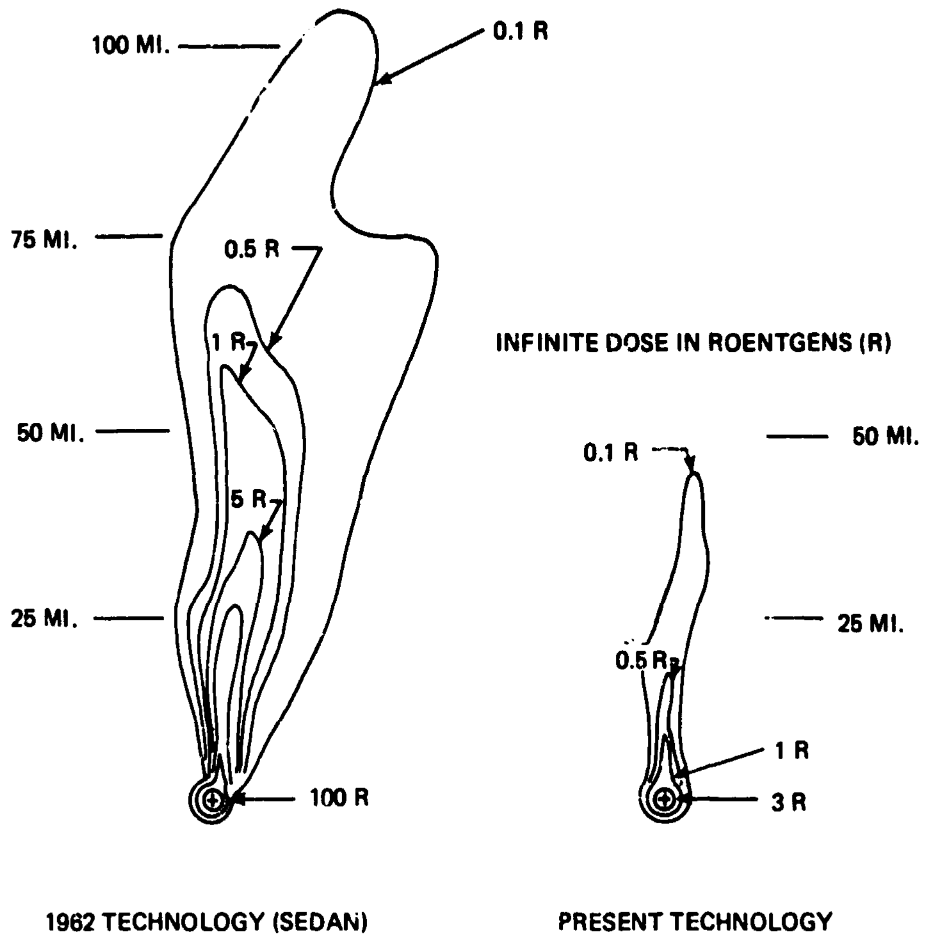
TABLE 6-3

ADDITIONAL EXPERIMENTS NOW CONSIDERED NECESSARY TO ESTABLISH FEASIBILITY OF NUCLEAR EXCAVATION FOR A SEA-LEVEL CANAL

Yield	Type of Experiment	Purpose
1 mt	Point charge (single crater)	To verify the predicted cratering behavior of saturated rocks; to obtain data on crater dimensions and explosion effects at yields comparable to those required for canal excavation.
5 to 7 charges @ 100 kt	Multiple point charges (row crater)	To verify concepts of the enhancement of row crater dimensions.
5 to 7 charges @ 100 kt	Multiple point charges (row crater)	To verify techniques of connecting row excavations smoothly.
5 to 7 charges @ 100 kt to 1 mt	Multiple point charges (row crater)	To demonstrate the techniques of nuclear excavation in a practical project away from the Nevada Test Site.

The third objective entailed predicting intensities and ranges of other effects—airblast and ground motion—caused by nuclear explosions. Each experiment supporting this study has provided an opportunity to examine mechanisms by which these effects are generated and propagated and to estimate how people, animals, and structures would respond to them. Results obtained have led to improvements in predicting intensities at which these effects may become hazardous. Recent tests have shown that under certain meteorological conditions, airblast effects would have a greater range than previously expected. Conversely, the predicted extent of objectionable ground motion effects has been reduced moderately. These phenomena require evaluation under prototype conditions before they can be defined precisely. Until such time, predictions must continue to be based on highly conservative assumptions which are reflected in the estimated costs for the planned nuclear safety program included in this study.

The fourth objective was to increase knowledge of the engineering characteristics of nuclear craters in terms of their long-range stability, not only as it relates to maintaining a navigation channel, but as it affects such structures as tidal gates and drop inlets. The stability of nuclear crater slopes has been demonstrated in desert alluvium and in a variety of rocks by experiments of up to 100 kilotons in yield. Possible stability problems of larger craters are discussed in the next section. Post-detonation investigation of the lips and fallback of craters has provided valuable information on techniques for constructing facilities in and around nuclear excavations.



Relative size of fallout patterns from Sedan, a 100-kiloton explosive detonated in 1962, and a theoretical 100-kiloton explosive of 1970 design.

COMPARATIVE FALLOUT PATTERNS 1962 – PRESENT

FIGURE 6-6

The ability to plan use of craters for navigation purposes depends on correct predictions of crater size and shape. Most craters have exhibited the general hyperbolic shape* on which the conceptual canal designs in this study have been based. The Technical Associates have suggested, however, that at substantially greater explosive yields than have been detonated to date, a phenomenon called air liquefaction might affect the crater formation process. This phenomenon has been observed occasionally in large naturally-occurring slides of broken rock where the permeability of the mass was sufficiently low to entrap air which supported the sliding material, causing it to flow as a liquid.† If this were to occur in a large nuclear excavation, the crater shape might be altered to leave a flat, shallow excavation whose depth might be insufficient for a navigable channel. A megaton-range experiment is required to determine whether the typical hyperbolic crater cross section would be preserved at high yields and whether modifications would need to be made in detonation plans to account for this. Such an experiment also would produce slopes with heights very close to those needed for a nuclear excavated canal and should, therefore, demonstrate the degree of their stability.

Status of nuclear excavation technology: The potential economic advantage of nuclear explosives for large-scale excavation projects is substantial. They should make possible the excavation of cuts of unprecedented size. Although the technology is based on what appears to be sound theory, this theory has been demonstrated by only a limited number of experiments at yield levels much smaller than would be needed for canal construction. The state-of-the-art allows predictions of results to be expected from excavation under conditions and at yields different from experience; however, these predictions do not carry the degree of confidence which must exist in an engineering feasibility study on which nationally significant decisions are to be based. The attainment of such confidence awaits the execution of at least those experiments outlined in Table 6-3. Under present constraints, it appears that accomplishment of this experimental program may take as long as 10 years.

The Soviet Union also has shown considerable interest in the use of nuclear explosives for peaceful construction purposes. Information on the full extent of the Russian experimental program is not yet in the public domain. However, the Soviet Union has held discussions on this subject with the United States and has released a series of technical papers which confirm that a vigorous program of research and experiment is underway. In general, the experience reported by the Soviets seems to confirm knowledge gained from the United States Plowshare program.

Of particular interest to this study is a well-formulated Russian proposal to employ a combination of nuclear and conventional excavation techniques in constructing the proposed Pechora-Volga Canal.[24] This project would divert the northward-flowing waters of the Pechora River to flow down the Volga to offset the lowering of the Caspian Sea. The Pechora-Volga Canal would be 70 miles long, 40 miles of which would be excavated by 250 nuclear explosives. Up to 20 explosives, with a maximum aggregate yield of 3 megatons, would be detonated simultaneously. This and other similar Soviet projects indicate that the Russians are moving ahead rapidly to develop and apply nuclear excavation technology.

*Schooner was an exception. See Figure 6-5.

†The high velocity of the landslides caused by the Peruvian earthquake in May 1970 strongly suggest that air liquefaction was involved.

Excavation in the Panama Canal was first tried on very steep slopes. The weak materials of the area would not stand on these slopes, resulting in slides such as the one shown in the lower center of this picture.

Model of 250,000 dwt ship undergoing tests to determine its handling characteristics in confined waters. Since there was only limited information available on this subject the Commission was forced to research the question.

One of the slides that closed the canal in 1915 is shown here. Slides were caused by too steep an excavation in weak clay shale materials.

High compression tests such as this provided information on the slope stability of materials found on the routes studied.

The Commission's studies considered some factors about which little was known. The slope stability of clay shale materials and the handling of large ships in restricted channels were two areas in which the Commission sponsored special studies to obtain information needed for their report.

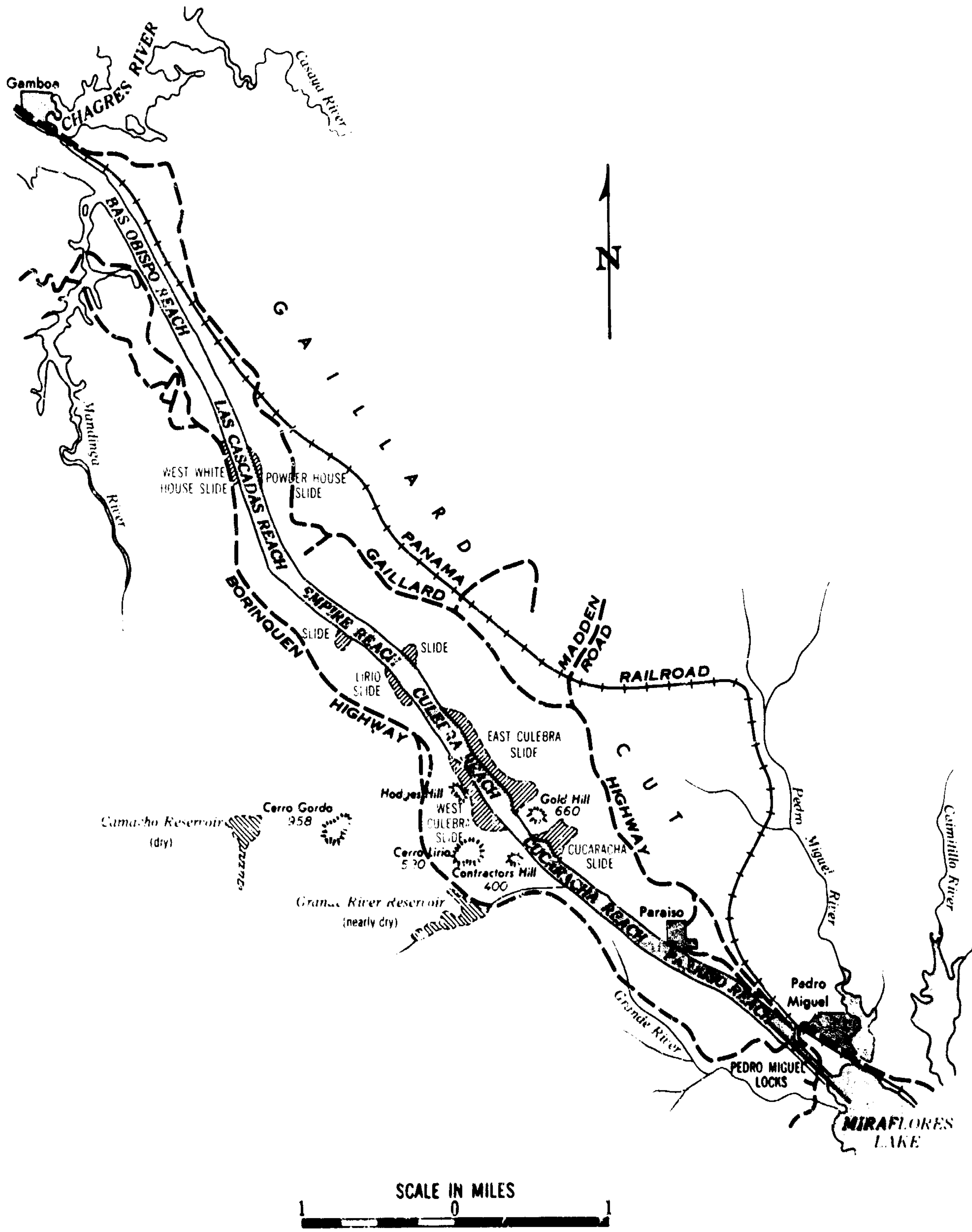
CHAPTER 7

SLOPE STABILITY

The cross section of a canal must be designed not only to meet navigational criteria but to minimize the likelihood of slope failures large enough to impede traffic. For estimating purposes slope criteria must be selected so as to be both conservative and economically attainable. This is a matter of engineering judgment Factors bearing on the exercise of that judgment are discussed in this chapter.

Excavated slope experience: The general slope design criteria used in preparing estimates of excavation quantities for this study have been extrapolated from data contained in previous studies [22,23] and from experience gained in the construction and operation of open-pit mines, quarries, road cuts, dam structures, and particularly the Panama Canal. Excavations, as deep as 2,280 feet and having various slope angles, were studied. They provided a guide to the slopes required along the proposed conventionally-excavated canal routes, which would attain a maximum height of about 600 feet. There is only limited applicable experience, however, because no previous project has ever faced the combined problems of slope height, soft rock, and tropical weathering conditions existing at the canal routes under consideration here.

Probably the best basis for stability predictions is found in the history of the Panama Canal. Surficial slides occurred there from 1884 to 1889 during construction by the first French company.[5] The second French company did little excavation in areas where weak materials had been encountered; consequently, the old slides were relatively inactive during the next 15 years. When the United States renewed canal excavation in 1905, surficial, or "mudflow" slides recurred. In 1907, when the depth of excavation exceeded 100 feet, massive slides began in the Gaillard Cut (Figure 7-1). Between 1908 and 1912 sliding continued and grew through progressive slumping, causing slopes to be cut back much flatter than the originally planned three vertical on two horizontal. More slides occurred between 1913 and 1916 when excavation was being completed through the divide. Water was admitted to the cut in October 1913, and in August 1914 the canal was opened to traffic, but landslides continued until gross movements of the East Culebra and West Culebra Slides eventually closed the canal from September 1915 to April 1916. Subsequent movements of the East Culebra Slide occurred, leading to other brief closings in 1917 and 1931; still another closure was caused in 1920 by movement of the Cucaracha Slide which first developed in 1913 south of the East Culebra Slide.[25] Since then, although the old slides have continued to show activity and new slides have developed, the canal has not been closed. The most recent significant movement occurred at Hodges Hill in 1968, immediately



SLIDE AREAS ALONG THE PANAMA CANAL

FIGURE 7-1

north of the West Culebra Slide. This movement now appears to have been arrested by improved surface and subsurface drainage.

Criteria for excavated slopes were developed for the Third Locks Project in 1939,[26] based on empirical data accumulated during construction of the Panama Canal. These criteria were modified during work on the project and again during the Isthmian Canal Studies of 1945-1947. The modified criteria were based partly on empirical data and partly on newly-learned principles of slope stability analysis. These modifications called for flatter slopes in the Cucaracha formation.

Between 1947 and the start of the present study in 1965, knowledge of slope stability was increased by experience gained in widening the Gaillard Cut and from the design and construction of earth embankments and dam excavations in the United States and Canada. Of particular interest were those projects involving clay shales, for it is in this type of material that the most significant slides on the Panama Canal have occurred. Thus, out of the problems of the canal, there has emerged better understandings of the loss of strength in excavated slopes resulting from unloading during excavation and of the progressive weakening of the slopes with time.[22]

The objective of the present study, as it pertains to slope stability along the proposed routes, has been to develop criteria for excavated slopes that would lead to excavation and cost estimates suitable for determining the feasibility of constructing a sea-level canal. To accomplish this, it was necessary to:

- Determine general geologic structures;
- Identify the types of materials, and their distribution;
- Determine the engineering properties of the materials, and their changes with time; and,
- Analyze experience gained from construction and operation of the Panama Canal in the light of current knowledge.

Investigations* made to attain these objectives have included:

- Surface geological reconnaissance;
- Drilling to obtain subsurface information and to recover disturbed and undisturbed samples for testing;
- A limited number of geophysical tests and paleontological analyses to aid in correlating strata;
- Laboratory testing to identify and determine the engineering properties of rock and soil materials;
- A review of slope stability experience in constructing and operating the Panama Canal;† and,
- Studies of steep slopes in other parts of the world.

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*Investigations for Routes 5, 8 and 23 were limited to reviews of information developed in previous studies, supported by a brief reconnaissance of each route.

†This has included limited field instrumentation in the Gaillard Cut and re-analysis of slopes that have failed. The areas studied were the East Culebra Slide, the West Culebra Slide, and the adjacent Model Slope. Studies of clay shale slopes in the United States and Canada also have been undertaken.

These objectives have been met to a degree that confirms the feasibility of excavating a sea-level canal by conventional means.

On the basis of laboratory tests and visual identification, materials encountered along the various routes have been placed in five general categories, corresponding with those used in previous studies:

- High quality rock (strong unaltered volcanic rock: basalts, agglomerates and tuffs);
- Intermediate quality rock (strong sedimentary limestones and sandstones and some slightly altered volcanic rocks);
- Low quality rock (silty and sandy claystones and altered tuffs);
- Soft rock (clay shales and soft altered volcanic rocks); and,
- Unconsolidated sediments (soft soils including Atlantic and Pacific mucks).

The distribution of the various materials was determined by correlating boring data and geologic mapping information. Drilling programs supplementing previous studies of Routes 10 and 14 aided in identifying materials along these alinements. Even with this additional information, correlation proved difficult because of the extensive faulting, volcanic activity, and alteration that have occurred in these areas. Analysis of slope stability along these routes was complicated by the presence of soft altered volcanic rocks and clay shales.

In addition to the usual effects of adverse geologic structure, the Panama Canal slides are attributable largely to the presence of clay shales. Consequently, special attention was given to investigating the nature of clay shales.[27] Comprehensive tests to identify and index clay shale properties were performed. These tests permitted correlation of materials found on the proposed routes with those existing on the Panama Canal and other projects. This, in turn, allowed the extrapolation of previous construction experience to the routes under consideration. Current testing methods show that very flat slopes would be required for long-term stability in clay shale. However, it is not yet possible in all cases to distinguish the geologic conditions under which these flat slopes would be required and those under which steeper slopes might stand safely throughout the project's life.

Recent field investigations on the present canal disclosed one significant feature that was not recognized previously: negative pore water pressure still exists in the clay shale masses of the East and West Culebra Slide areas. This condition suggests that the material may not have become fully stabilized since its loading was reduced by excavation, and that continuing movement may be expected until pore water pressures reach stable levels. For this reason, and because of jointing and faulting defects, prevalent in the formations under consideration, conservative criteria were adopted for slopes in clay shales. Additional study of slopes in the Gaillard Cut is required to improve current assessments of their long-term stability.

An empirical study of high clay shale slopes in the Missouri River Valley also was conducted as a part of the investigations of the feasibility of nuclear cratering.[28] The investigative procedures employed, including surface mapping, drilling, sampling, and testing, were coordinated with procedures used in investigating the canal routes. Although conducted primarily to provide a basis for assessing the stability of high slopes created by nuclear cratering in clay shale, this work contributed data which have proved useful in evaluating conventionally excavated slopes.[22,23,25]

Conventional excavation slope criteria: The slope criteria used in this study were recommended by the Technical Associates on Geology, Slope Stability, and Foundations. Cross sections used for feasibility determination and cost estimating purposes are shown in Figures 7-2 and 7-3. Except for soft rock, these criteria are identical to those recommended by the 1947 report.[12] For slopes in soft rocks, previous criteria have been modified, as shown in Figure 7-3, for those routes which are located so close to the present canal that they involve relatively high risks of slides that might interfere with the Panama Canal.

On routes remote from the existing canal, an appropriate and economical method of providing stable slopes in soft rock might be to flatten slopes progressively, utilizing an observational approach.* However, slopes on Route 14 must be excavated initially with a sufficient margin of safety to ensure a high probability of no interruptions to traffic from slides into the Panama Canal, or loss of Panama Canal water from slides into the new cut.

Nuclear excavated slopes: Nuclear excavation produces an apparent crater which is approximately hyperbolic in cross section and is bounded by fragmented material comprising the fallback zone. This material is deposited within the true crater at an angle somewhat flatter than its natural angle of repose. In the rupture zone the original geologic structure is disrupted, the medium permanently displaced, and many new fractures created. An explosively excavated cut is a very complex structure and crater slope stability predictions must be made indirectly or empirically by comparison with similar man-made and natural slopes and by observation of existing craters.[30,31]

Except in soft materials, the fallback and rupture zones of explosive cuts are significantly more permeable than the surrounding undisturbed material and their resistance to groundwater flow is substantially less than that of mechanically excavated slopes. Therefore, cratered slopes in hard rock tend initially to be free draining, a condition which reduces their susceptibility to the adverse effects of seepage pressures.

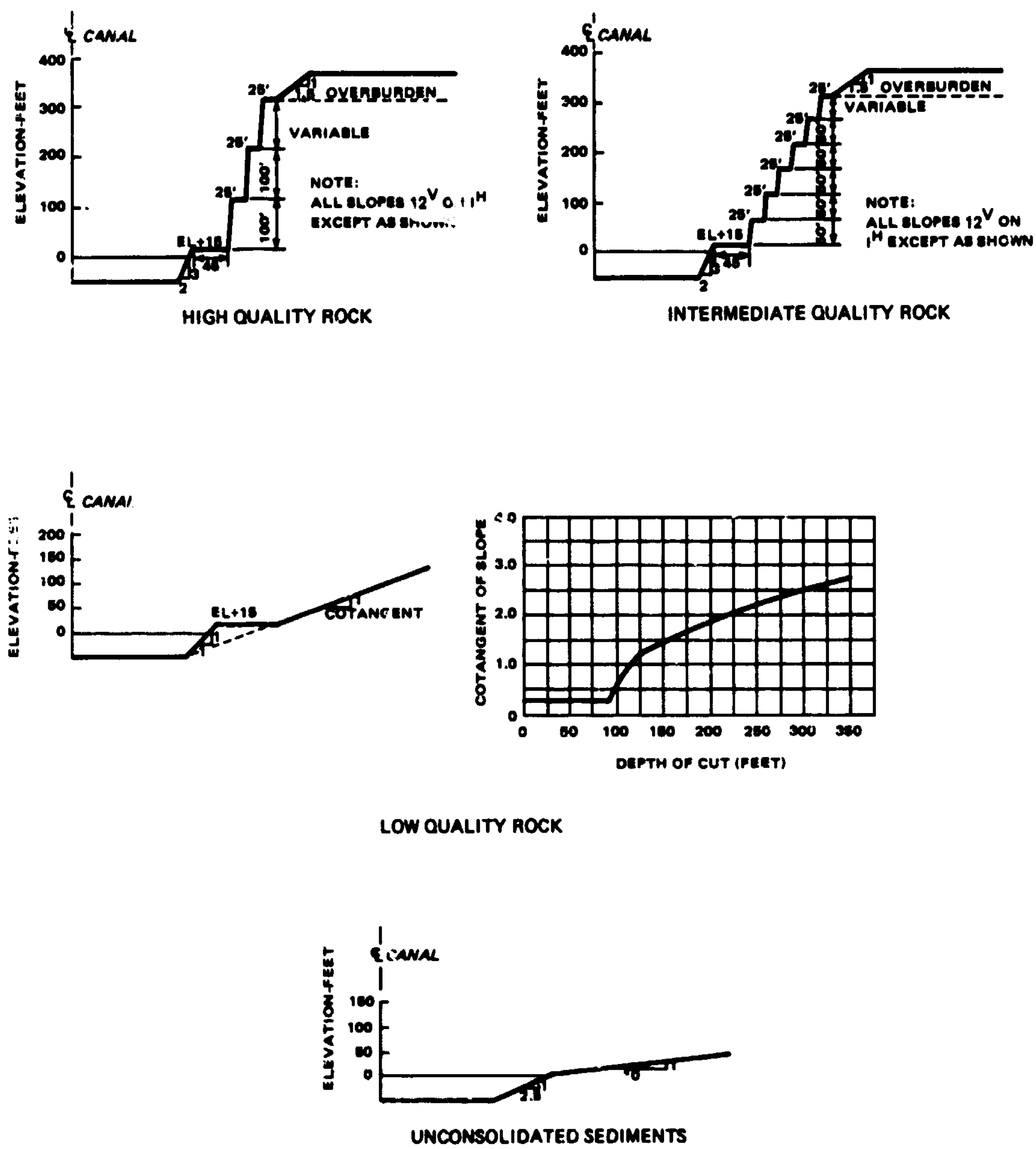
Crater slopes possess a number of features which are generally desirable in terms of stability

- The slopes are buttressed by deposits of broken material which have significant margins of safety against deep-seated sliding;
- Many pre-existing major planes of weakness have been disrupted; and,
- The materials within and behind the slopes should be initially free draining and might remain so for the life of the canal.

Studies of craters produced to date suggest that explosive excavations in hard rock will remain stable over the life of most excavation projects. However, all existing nuclear craters in rock are in a desert environment and none is deeper than 250 feet.† In contrast, the slopes of an Isthmian sea-level canal would be exposed to a tropical environment and their

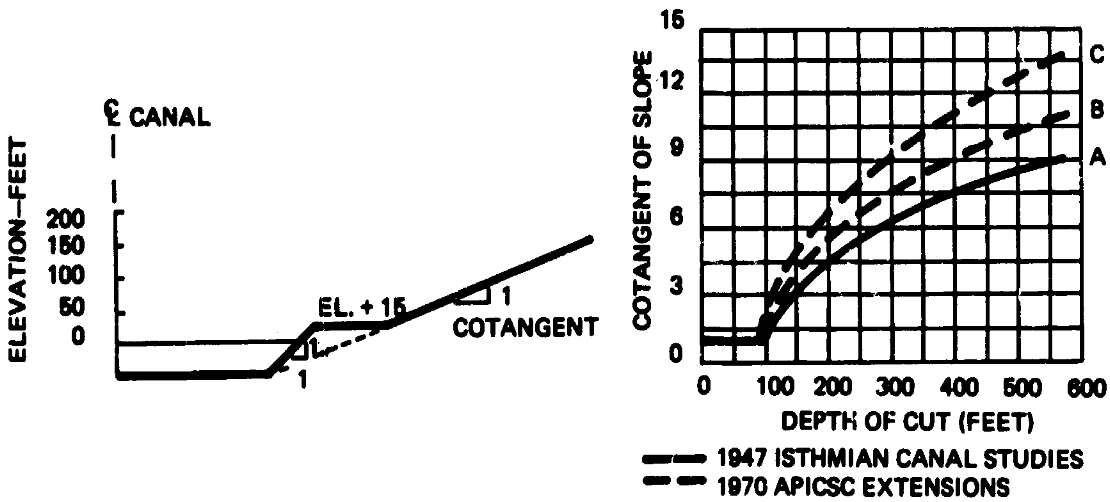
*The observational approach would be applied by designing the steepest slopes that could be developed in accordance with the knowledge available at that time. The stability of the slopes would be observed closely during construction. The results of earlier excavation would be used as a guide to the design and construction of the remainder of the excavated slopes. This was the approach used in constructing the Panama Canal. The objective of this approach would be to reduce the excavation volumes from those shown in this report.

†Total depth from top of lip to bottom of apparent crater for Schooner. See Table 6-2.



EXCAVATED SLOPE CRITERIA FOR HIGH, INTERMEDIATE, AND LOW QUALITY ROCK AND UNCONSOLIDATED SEDIMENTS[24]

FIGURE 7-2



Curve A—For locations where the canal would be remote from the existing canal. (The existing canal would be available for use during a proving period.)
Curve B—For locations where the canal would be separate from the existing canal but in close proximity. (Excavation would be performed in the dry and gradual drainage would be possible during construction. An observational period would be available during construction, prior to the canal becoming operational.)
Curve C—For locations where the canal would be adjacent to the existing canal in an area with a history of slides. (The area would have undergone long term creep, and the slopes would be subject to rapid drawdown. The continued maintenance of traffic on the Panama Canal during construction is required.)

EXCAVATED SLOPE CRITERIA FOR SOFT ROCK[26]

FIGURE 7-3

maximum excavation might be as deep as 1,900 feet, i.e., a 1,200-foot apparent crater depth plus a lip height of 700 feet. Because of these differences, extrapolation of cratering experience to the analysis of slope stability for a nuclear excavated canal is tenuous and uncertain. Significant differences between experience to date and potential canal excavation requirements are:

- Heights of slopes for the canal would be more than five times as great as those in the largest existing nuclear crater;
- Weathering of crater slope materials in the isthmian tropical environment would be much more severe and rapid than at the Nevada Test Site; and,
- Groundwater is abundant and generally close to the surface in the Isthmus, whereas in Nevada it is well below the existing craters.

There are indications that with increasing explosive yields, fallback would be denser than that observed to date. As yields increase, fallback impacts from greater heights and acts more effectively as a buttressing agent. On the other hand, this denser material may have reduced permeability which could inhibit groundwater flow and increase seepage pressures.

As discussed previously, it has been suggested that, with increasing yields, air liquefaction of the fallback might occur. This would tend to produce flatter and broader craters than those predicted for this study. The effect of this phenomenon on slope stability could be favorable, in that initially flatter slopes would be more stable; or it could be unfavorable because of reduced buttressing of the rupture zone.

Natural rubble slopes were examined[32] to determine indications of expected long-term crater slope performance. Talus deposits* were found to be the natural rubble materials most closely resembling crater fallback; however, crater slopes with more homogenous mixtures of fragment sizes, are expected to have flatter inclinations and greater initial stability than talus slopes. Long-term adjustments of crater slopes might be experienced as a result of settlement, surficial erosion, and downward migration of fine grained materials. Data on talus deposits in tropical regions are limited.

Geological samples from Routes 17 and 25 were subjected to slaking tests to ascertain their susceptibility to weathering.[33] Many of them slaked, indicating that weathering of fallback would occur; however, the rate at which weathering would take place cannot be predicted. Crater slope adjustments are expected to occur as a series of gradual ravelling or surficial adjustments rather than through deep-seated slides. This, coupled with the excess channel depths produced by nuclear excavation, suggests that weathering of fallback slopes would not constitute a serious problem.

The influence of groundwater on crater slope stability can be evaluated only qualitatively at this time. The increased permeability of the fallback and rupture zones tends to minimize the likelihood of excessive hydrostatic pressures in the crater slopes; however, there are no experimental data on which to base estimates of the rates of groundwater flow through either the fallback or rupture zone. Cratering experiments in saturated, permeable rocks are needed to obtain the data necessary for quantitative analysis of groundwater inflow to crater slopes.

Over a long period of time clay shale slopes tend to reach the angle of residual internal friction of the clay shale, which may be as low as 6 to 10 degrees. Excavations in this material would require flatter slopes than would be produced by normal cratering techniques. Small-scale experiments with chemical explosives suggest that explosive excavation by multiple-row arrays could produce flat-sided cuts, but the outlook is poor for approaching 6 to 10 degree slopes in deep cuts with nuclear explosives. Therefore, in this study it was assumed that all clay shale materials would be excavated by conventional means.

Appraisals were made of stability of nuclear excavated slopes along Routes 17 and 25.[33] These appraisals were based on data acquired at the sites and on predictions of expected slope height and cratering characteristics. Each route was subdivided into segments having similar properties, and the slope stability of each segment was estimated. These appraisals identified intervals of soft rock along each route where significant slope adjustments might occur during the life of the canal. Special attention must be given to these areas during the pre-construction investigation and design phases of canal construction.

Not enough data are available to justify any confidence in estimates of slope stability along Routes 8 and 23.

*A sloping pile of rock fragments at the foot of a cliff.

CHAPTER 8

CHANNEL DESIGN AND TRANSIT CAPACITIES

General criteria for channels were derived from traffic projections developed in Annex IV, *Study of Interoceanic and Intercoastal Shipping.*[34] They were accepted by the Commission as a basis for conceptual design. In essence, these criteria established the following requirements:

- Ship size: The canal must be capable of transiting ships up to 150,000 dwt* routinely under all conditions, and occasional ships up to 250,000 dwt without major expenditures for additional construction. Underwater structures built during initial construction must be adequate for 250,000-dwt ships.†
- Transiting requirements: Initially, the canal must be capable of transiting approximately 35,000 ships per year. Expansion must be possible to accommodate 60,000 annual transits by the year 2040, and an ultimate traffic volume of about 100,000 annual transits.

Customarily, channel widths are designed in accordance with empirically-derived criteria expressed in terms of the maximum beam of transiting ships and the desired traffic patterns. Under these criteria, channel bottom widths vary between about 3 beams for a canal carrying one-way traffic to 7.6 beams for 2 lanes of traffic traveling simultaneously in opposite directions.[35] Channel depths often are designed at 110 percent of maximum ship draft.

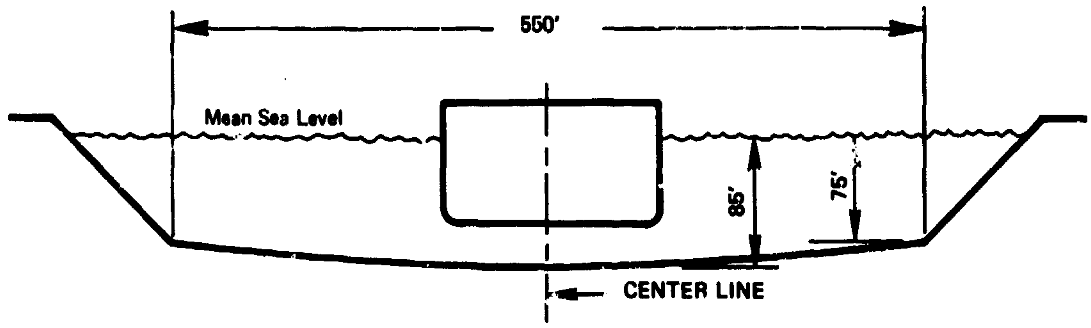
As will be discussed later, recent studies show that a sea-level canal should be 550 feet wide with a parabolic bottom 75 feet deep at its edges and 85 feet deep along its centerline in order to meet the Commissions's criteria on ship size. (See Figure 8-1.) This single-lane channel is referred to as the "design channel." Based on current projections of shipping for the year 2000, a canal having these dimensions would be large enough to pass about 95 percent of the world tanker fleet, an even greater portion of the bulk carriers, and all

*Deadweight tons (dwt). The deadweight tonnage of a ship is its fully loaded capacity in long tons (2,240 pounds), including cargo, fuel, and stores, but not including the weight of the ship itself.

†Approximate dimensions for 150,000- and 250,000-dwt ships are:

Deadweight tons (dwt)	Length (ft)	Beam (ft)	Draft (ft)
150,000	970	148	55
250,000	1110	175	67

The 150,000-dwt ship with dimensions as shown has been designated the "design ship."



The design channel at mean tide, showing a 150,000 dwt ship. Channel side slopes vary, depending on the slope stability criteria. At extreme low low tide, the water level at the Pacific entrance of a canal could be 10 feet lower.

FIGURE 8-1

freighters.[34] The approximate size distribution* of ships expected to use an isthmian sea-level canal at that time is shown below:

Ship Size Group 1000 dwt	Percentage of Ships Using Canal in the Year 2000 in each Size Group
0 - 10	28
10 - 25	53
25 - 50	11
50 - 100	6
100 - 150	1
150 - 250	1
	100

A suitable channel excavated by nuclear means would have a width of at least 1,000 feet at a depth of 75 feet, and a hyperbolic cross section considerably deeper at mid-channel than a conventionally excavated section of equal width. Such a channel would impose fewer restrictions on navigation than the design channel. For that reason, unless otherwise indicated, the following discussion relates to the conventionally excavated design channel, through which ships would move in convoy.

A rectangular 1400- by 85-foot channel has been selected for the canal's ocean approaches. These dimensions would permit large ships to pass one another at reasonable speeds, would give added maneuver room in open waters, and would be relatively inexpensive to excavate. A small portion of the initial construction cost might be deferred by constructing the approaches to a 1,000-foot width which should be adequate during the early years of sea-level canal service.

*This distribution was developed from data presented in Annex IV, *Study of Interoceanic and Intercoastal Shipping*, using the assumption that 46 percent of the cargo passing through the canal would be carried in freighters.

Maximum transit capacity could be obtained in a canal wide enough throughout its entire length to accommodate two opposing lanes of traffic; however, the costs of constructing this configuration by conventional means appear prohibitive and the canal's transiting capacity would far exceed foreseeable demands. Two smaller, less costly configurations have been found satisfactory for most of the routes considered; these are the single-lane canal (the one-way configuration) and the single-lane canal with two separated one-way passing sections (the bypass configuration). Both configurations include two-lane ocean approach sections which later could be extended inland from either ocean to increase capacity by shortening the one-way sections. The choice of configuration depends upon the capacity desired, the route's length, the topography and geology, and the current velocities considered acceptable.

Ship maneuverability in confined waters: To ensure positive steering at slow speeds, a ship's propeller must maintain an adequate flow of water past the rudder. Generally, ships smaller than 50,000 dwt under their own power must proceed at speeds of at least 4 knots while larger vessels must maintain at least 5 knots.

A ship moving through confined waters encounters greater hull resistance than one operating in unconfined waters. In the design channel a combination of this phenomenon with the loss of propulsive efficiency which occurs in confined waters would reduce the maximum attainable speed of a 150,000-dwt ship, capable of 16 knots on the open sea, by almost 6 knots; and the speed of a 250,000-dwt ship of similar capability by 8 knots. Smaller ships would be less affected. (See Figure 8-2.)

If a vessel shorter than the canal width were to run aground, it could swing parallel to the bank and avoid blocking traffic. However, most ships would be longer than the width of the canal and might come to rest across the canal after grounding, blocking it completely. To minimize the likelihood of such an occurrence, ships longer than the canal's width* would be accompanied by one or more tugs.

Tug assistance also would be needed to stop heavier vessels in an emergency because water resistance alone would not be sufficient and the application of reverse power in narrow channels is hazardous. When reverse power is applied, flow past the rudder is greatly reduced and the pilot loses much of his ability to steer the ship. In addition, almost all ships, including the large tankers and bulkers which are the most difficult to stop in a canal, have only a single screw. Application of reverse power to such a ship causes its stern to move laterally. A tug astern could be used to oppose this lateral force, permitting a part of the ship's reverse power to be used in stopping.

Stern anchors have been considered as a source of stopping force. They are effective at land speeds of two knots or less; at greater speeds, either the anchor will drag, or its chain will run out completely and be lost overboard. In view of the limitations of this stopping technique and because some ships do not have stern anchors, stopping distances used in this study depend on the use of tugs not on anchors.†

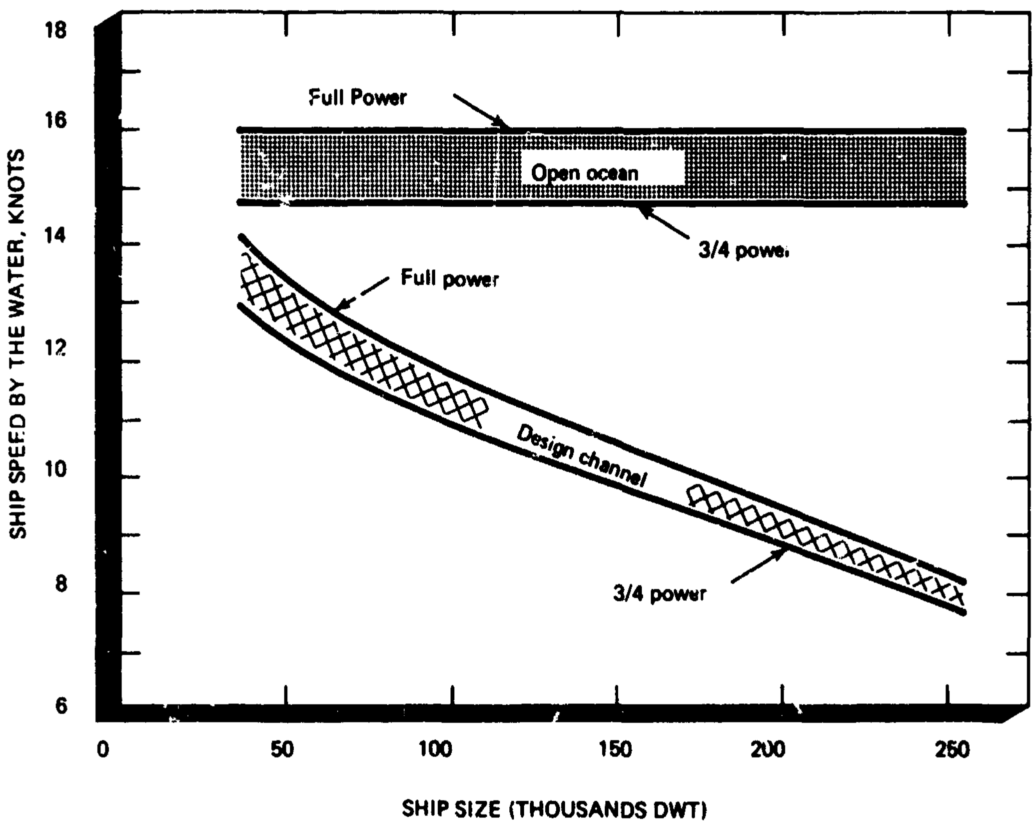
*The canal width would be measured at the depth of the ship's keel since the sloping banks of the canal would allow a greater effective width for a shallow draft ship than for a deep draft one.

†Stern anchors might be employed effectively when the ship's land speed has been reduced to 2 knots and the windlass brake can exert a measured pull on the anchor chain as it pays out. They might be made a requirement for passage of large ships, or could be provided on the tug which normally would ride astern of the ship it accompanies.

Tugs also would be used to hold back large ships in following currents. Without increasing land speed, this would permit more propeller revolutions, increasing flow past the rudder and improving the ship's steering.

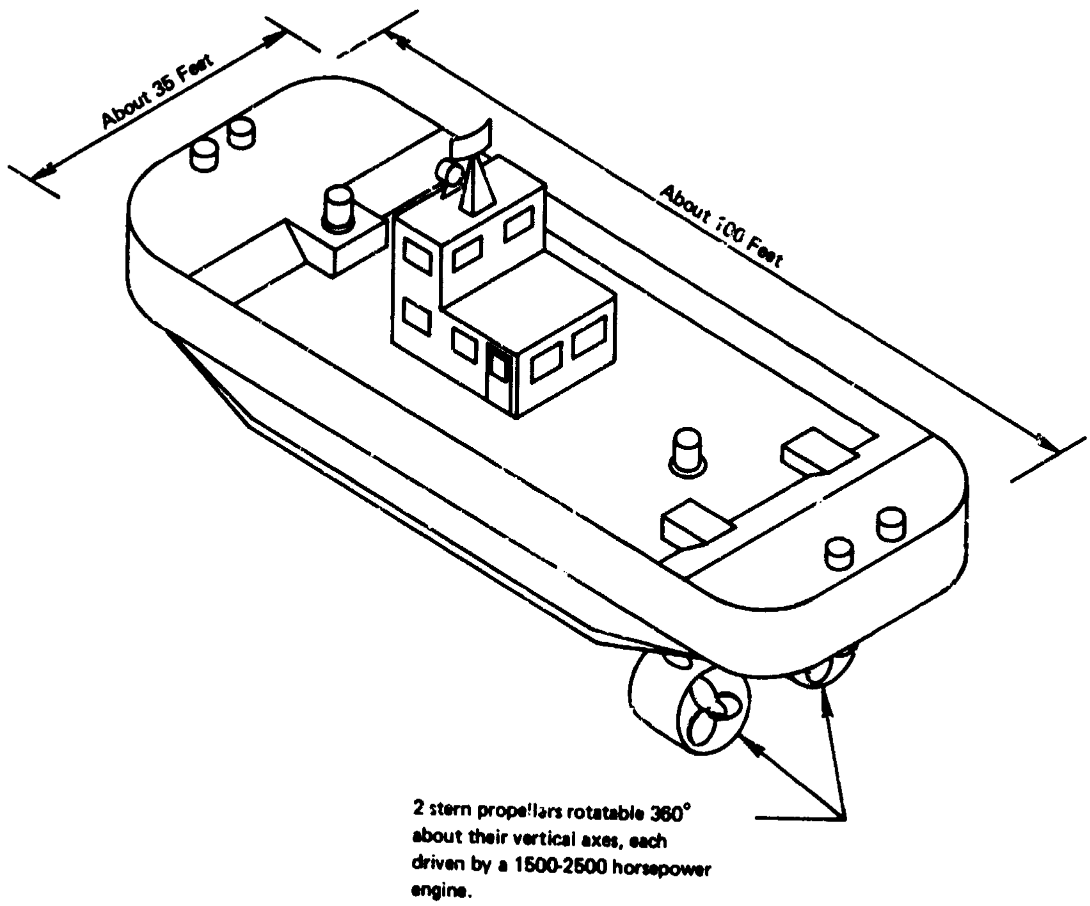
Tugs used in a sea-level canal should be highly maneuverable and able to exert full thrust in all directions. Such tugs (See Figure 8-3.) might employ a steerable right angle drive with a fixed shroud around the propeller to increase thrust (a Kort nozzle). Small tugs of this type are now in use and the development of larger tugs to be employed in the canal should not require a significant development effort. To ensure that adequate tugs would be available when a sea-level canal is opened to traffic, their design and construction should be undertaken at an early date. Prototypes could be tested in the Panama Canal and further improvements made before the required tug fleet is procured.

Tidal currents: The transiting capacity of a canal depends on the ships' speed relative to the land. This speed is directly dependent on the speed which the ships can safely attain in the canal and on the velocity of canal currents.



Estimated maximum attainable speed of a ship on the centerline of the design channel for ships capable of 16 knots in open seas.

FIGURE 8-2



Conceptual design of a sea-level canal tug.

FIGURE 8-3

Because an isthmian sea-level canal would form an open waterway connecting the Atlantic and Pacific Oceans, any difference between the levels of these two bodies would induce currents in the canal. Measurements made over an extended period in the vicinity of the Panama Canal show that the average level of the Pacific is above that of the Atlantic 55 percent of the time, and that mean sea level (msl) at the Pacific terminus is approximately 0.75 feet higher than that on the Atlantic.[36] Tides along the Atlantic Coast of the Panamanian Isthmus range up to 1.3 feet above and below msl, while on the Pacific Coast they vary between about 5 feet above and below msl to about 10 feet above and below msl.* These tides would generate periodically reversing currents through a sea-level canal, with a net flow from the Pacific to the Atlantic caused in part by the average higher level of the Pacific Ocean. (A freely floating object would take about two and one-half days to transit an open sea-level canal at the location of the Panama Canal.)

Figure 8-4 shows tidal stages recorded during a typical week at the entrance of the Panama Canal.

Currents in a sea-level canal, like the tides, would be cyclic with a 12.4-hour period. At all points along the canal, they would change direction approximately every 6.2 hours, with their velocities depending on the height and phasing of the tides, the size and variation of the cross section, the length of the channel, and the roughness of the canal banks and bottom. Figure 8-5(a) shows the 24-hour trace of an extreme Pacific Ocean tide. Figure 8-5(b) shows the variations in currents which this tide would cause in a 36-mile-long canal along Route 10 with the design channel section. The dashed diagonal line AB in the figures shows the progress and the speed in the water of a ship transiting this canal at a constant land speed of 7 knots.

Channel design: The design of a sea-level canal must consider:

- Speed of the ship through the water. This varies with the power applied to the propeller and governs safe navigating conditions.

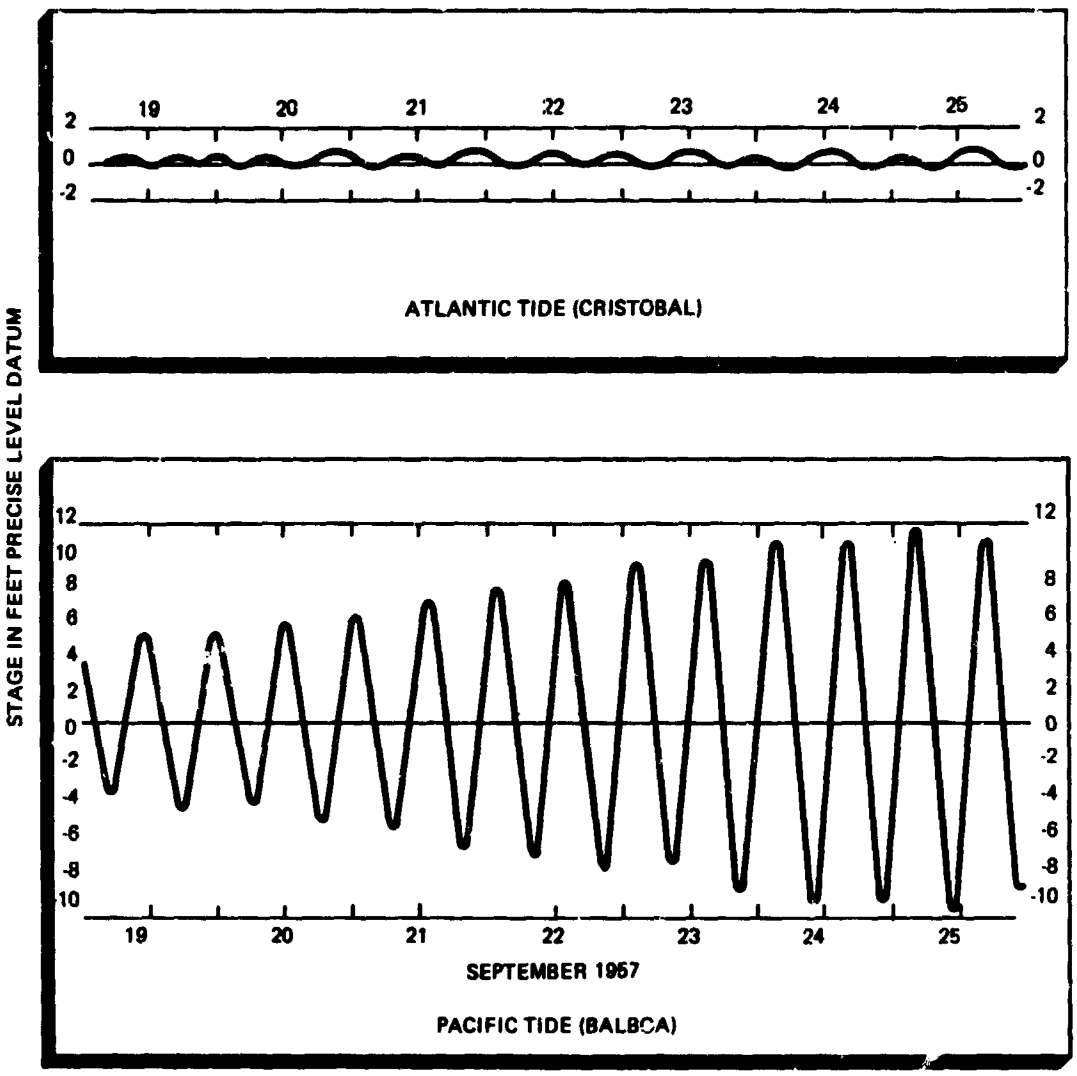
- Speed of the ship by land. This is the algebraic sum of the ship's speed through the water and the tidal current. It governs transiting capacity.

In the opinion of Panama Canal Company pilots, a 7-knot land speed† would be reasonable for all ships using a sea-level canal with tugs used where appropriate. A faster land speed might be satisfactory with adequate safety precautions. Seven-knot land speed is compatible with speeds maintained in other major confined waterways. A ship with a 7-knot land speed would travel at 7 knots in slack water, 11 knots by water against a 4-knot head current, but only 3 knots by water in a 4-knot following current.‡

*Greater tidal ranges occur 5 or 6 times each year. The maximum recorded tidal range at the Pacific entrance of the Panama Canal is 21.7 feet.

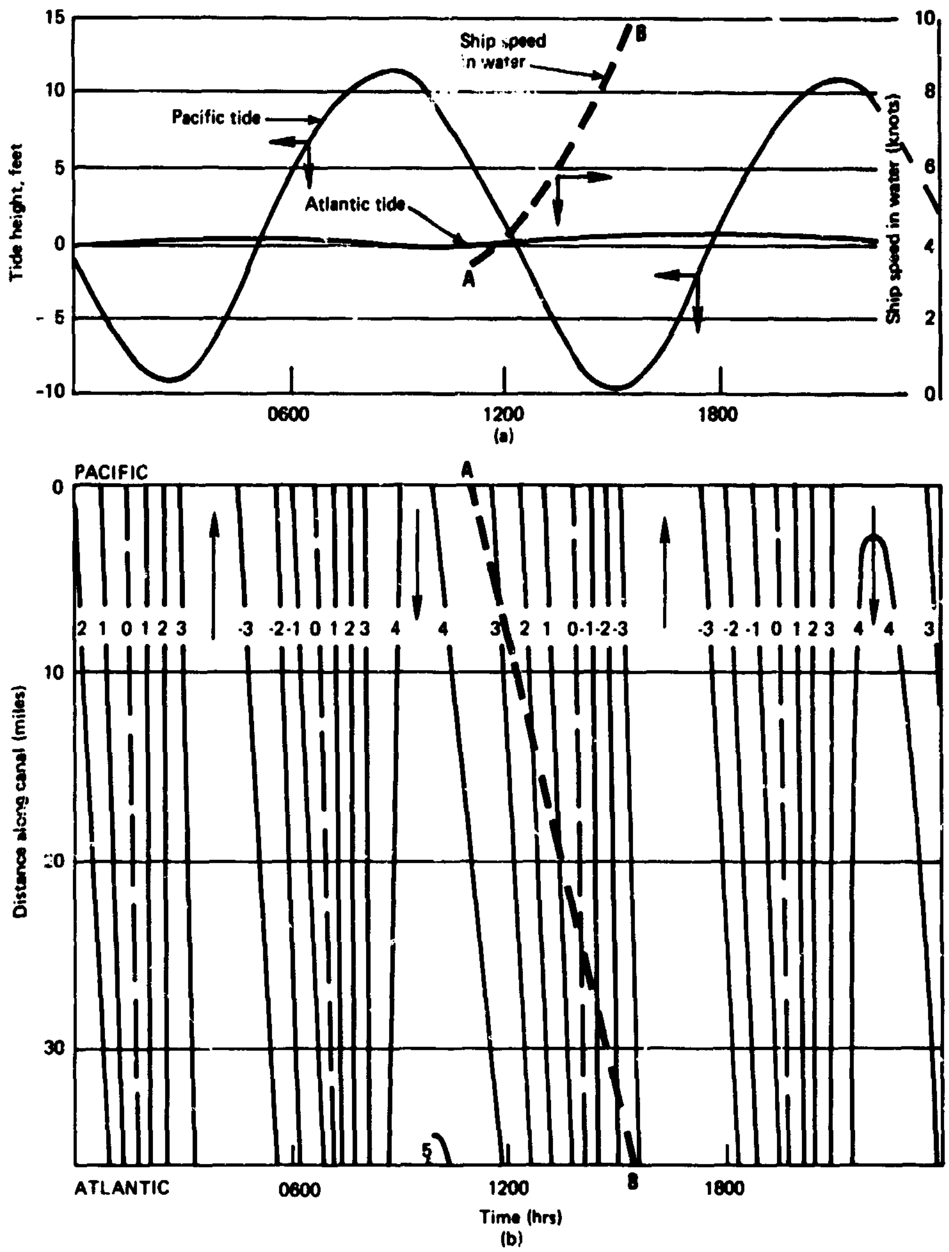
†Land speeds of 6 to 8 knots were prescribed in the Gaillard Cut when it was 300 feet wide. The larger ships were required to travel at lower speeds. Considerations other than ship safety restricted the speed of small ships to 8 knots in the narrow cut. The cut has since been widened to 500 feet.

‡Although the Panama Canal is usually considered to be without current, surges up to 1.5 knots occurred in the 300-foot-wide Gaillard Cut when the culverts were opened to fill the Pedro Miguel locks. Since the cut was widened to 500 feet, the surges have been reduced. Tides cause currents of up to 2 knots in the Pacific approach.



Pacific and Atlantic tide traces
(from Panama Canal Company records)

FIGURE 8-4



Top figure: Extreme Pacific tide height (a). Ship speed in the water required for a land speed of 7 knots is shown by the dashed line A, B.
Bottom figure: Resulting currents in a 36-mile canal on Route 10, with design channel (b). Numbered lines show currents in knots. Arrows denote current direction. Ship enters from Pacific (A) at 1100 hours in a 3-knot following current and reaches the Atlantic (B) at 1530 hours in a 3-knot head current.

FIGURE 8-5

Friction losses and diminished propulsive efficiency would limit the maximum speed by water attainable by a typical 150,000-dwt ship in the design channel to about 11 knots. Thus, if a land speed of 7 knots is to be maintained, the maximum allowable head currents cannot exceed 4 knots. Similarly, if unassisted large ships are to maintain steerage and, at the same time, not exceed 7 knots by land, the maximum allowable following current would be 2 knots; with tug assistance, following currents of 4 knots or more would be acceptable. Therefore, the channel has been designed to permit ship speeds by land of 7 knots, with a maximum allowable head current of 4 knots. Such a channel could accommodate ships traveling at 7-knot land speed in 4-knot following currents, if assisted by one tug.

Selection of the design channel cross section was based on an extensive search of pertinent technical literature, mathematical and hydraulic model studies performed for the Commission by the Stevens Institute of Technology and the Naval Ship Research and Development Center, and analyses of traffic experience in the 300-foot-wide portion of the Gaillard Cut of the Panama Canal.* Panama Canal data were of particular importance because they reflect implicitly such factors as pilot capability, accident experience, and the effects of banks similar to those of a sea-level canal, thereby providing means for correlating predictions with operating experience. The results of these investigations are summarized in the design curves of Figure 8-6† which show channel depth and width as functions of ship size and safe operating speed in water.

Figure 8-6 can be used to estimate:

- Channel dimensions required to enable ships of the maximum sizes specified by the Commission to maintain a particular speed in water safely; and
- Safe speeds in water for these ships through a range of channel dimensions.

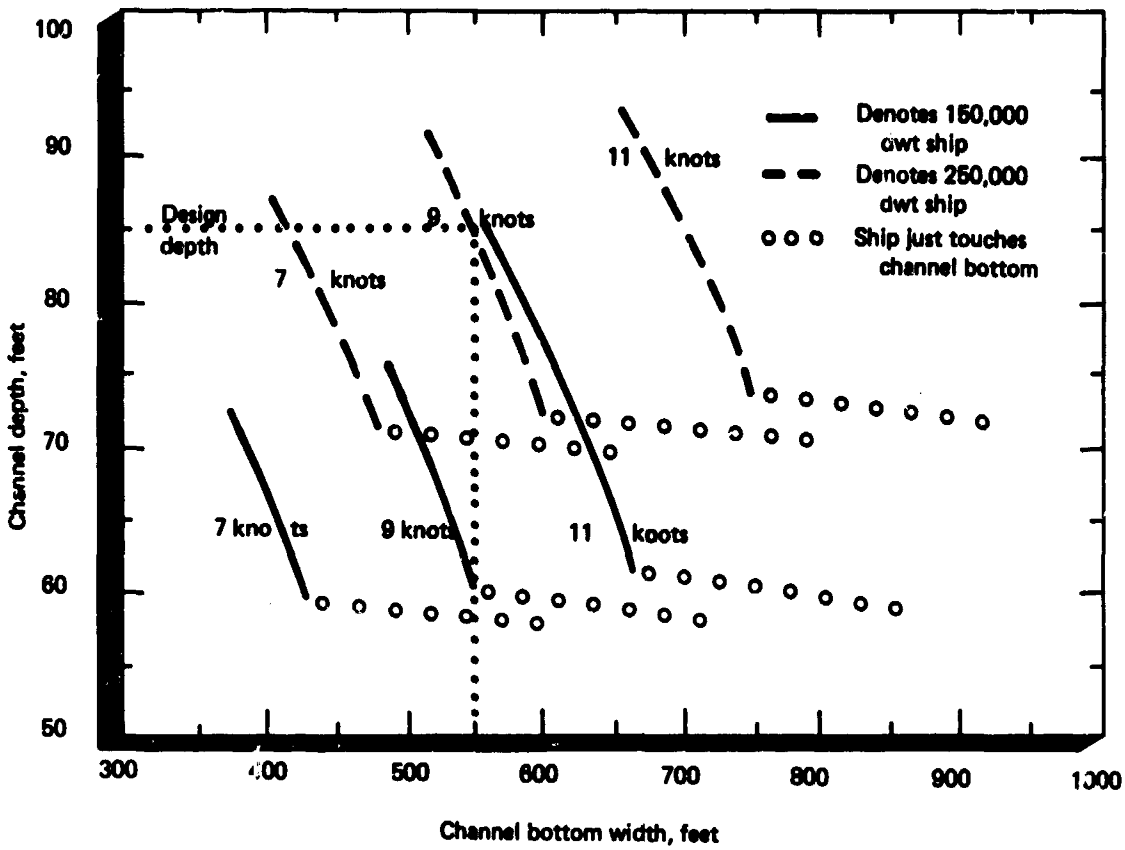
Selection of the design channel was based on the relationships shown in Figure 8-6. The 75-foot channel edge depth would provide clearance below the bottom of a 250,000-dwt ship, should it approach the edge of the channel for any reason during most tide levels. Deepening the center of the channel by 10 feet would provide ample clearance below the keel while the ship is on its usual centerline position.‡ The design width is 550 feet. The resulting 550- by 75/85-foot channel would permit a 150,000-dwt ship to make 7 knots by the land against 4-knot currents. A 250,000-dwt ship could travel safely only at speeds up to 9 knots in the water, restricting transit of such ships to periods of favorable currents. Calculated safe speeds in water for various size ships moving through the design channel are shown in Table 8-1.

The bottoms of navigation channels in tidal regimens usually are made parallel to the water surface at low tide. Application of this practice to an isthmian sea-level canal would result in a bottom elevation about 10 feet lower at the Pacific end than at the Atlantic end because of the greater range of Pacific tides. Since the sloping bottom would lead to

*A 60,000-dwt ship in the 300-foot-wide reach of the Gaillard Cut provided, in effect, an approximate hydraulic model of a 250,000-dwt ship in the design channel.

†The relationships shown on Figure 8-6 have not been verified by full-scale tests.

‡The parabolic bottom used in conceptual designs and cost estimates presented in this report involves approximately 7 percent less excavation than a flat-bottomed channel 85 feet deep.



Curves showing combinations of channel dimensions providing equal navigability for tankers traveling on the channel centerline at the indicated speeds through the water. The dashed line shows the design channel which permits a 150,000 dwt ship to transit safely under all conditions and a ship as large as 250,000 dwt to transit safely under selected conditions.

Channel design curves

FIGURE 8-6

stronger tidal currents and more excavation, it was not adopted for this study. Instead, a bottom centerline 85 feet below and parallel to mean sea level was adopted. The water depth at the Pacific terminus would fall periodically below 85 feet, precluding safe transit of the largest ships at all times. Such conditions would last for a small portion of a tidal cycle and would affect less than one percent of all transiting ships. The effects of this limitation could be all but eliminated through careful scheduling of ship transits through the canal.

TABLE 8-1

ESTIMATED SAFE SPEEDS OF LARGE SHIPS TRAVELING UNASSISTED IN THE DESIGN CHANNEL

Ship Size (dwt)	Approximate Percent of Ships Larger Than Indicated Size Using the Canal in Year 2000	Minimum Safe Speed in the Water (Knots)	Maximum Safe Speed in the Water (Knots)
50,000	8	4	More than 11
100,000	2	5	More than 11
150,000	1	5	11
200,000	0.2	5	10
250,000	Less than 0.1	5	9

Mitigation of the effects of currents: Current velocities place three requirements on ship navigation. Every vessel must be able to:

- Maintain controllability in both head and following currents;
- Maintain the required land speed in the strongest head currents; and,
- Stop safely in the strongest currents.

If only a few ships were unable to meet these requirements, these ships could be scheduled to avoid strong currents; however, if substantial numbers were affected by these conditions, other measures would have to be taken, such as reducing current velocities to an acceptable level, or increasing ship controllability by employing tugs or other external means.

Earlier investigations and those made for this study indicate that large ships could be navigated safely through the design channel in currents up to 4 knots. Conclusive evidence to support this is lacking and accordingly, methods for reducing current velocities have been sought. Possibilities include constructing retarding basins at the canal ends, increasing the channel length, widening the reach in which high velocities would occur, increasing the hydraulic roughness of the channel, installing locks, and employing tidal check gates. The most promising solution to this problem appears to lie in the use of tidal gates which would prevent unacceptably strong currents by limiting the length of canal open to Pacific Ocean tidal action. The gates could remain open during tidal cycles producing relatively low

currents. Some possible gate configurations are illustrated in Figure 8-7. Until such time as prototype experience verifies that large ships can operate safely in stronger currents, tidal checks would be used to ensure acceptable conditions. This could be done at relatively moderate cost.

Figures 8-8 and 8-9 illustrate how tidal checks would be incorporated into the two basic canal layouts evolved for this study, i.e., the one-way configuration and the bypass configuration. For each configuration, tidal checks would be provided in at least two locations. The distance from the gate on the Atlantic side to the Pacific entrance would determine maximum velocity at the Pacific entrance; the closer the Atlantic side gate to the Pacific, the lower the velocity.* For the design channel on Route 10, for example, the gate on the Atlantic side should be situated no more than 28 miles from the Pacific entrance in order to limit currents to two knots.† This gate has been planned for installation only 25 miles from the Pacific so as to permit the last ship in a convoy to clear the channel while the first ship in the next convoy in the opposite direction approaches the gate as it opens on the tidal cycle. A second gate would be placed as close to the Pacific end as practicable to allow the longest possible convoys.

On short sea-level canal routes such as Route 10, currents without tidal checks would be appreciable for a large part of the time, and if navigation were not possible in currents stronger than two knots, transit capacity would approach zero. Tidal checks would be required to achieve the design transit capacity under these circumstances.

Because of their great size and weight, the tidal checks could not be shifted to an open position except when the water levels on both sides of the gate were approximately the same. This condition would occur regularly every 6.2 hours when the Pacific is at the same elevation as the Atlantic. The gates would therefore be shifted at intervals of multiples of 6.2 hours as indicated on Figures 8-8 and 8-9.

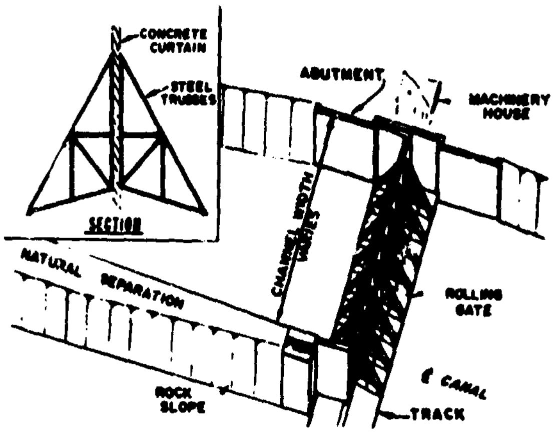
Figure 8-10 shows the currents in a one-way canal configuration on Route 10 with tidal checks 25 miles apart. The effect of tidal checks can be seen by comparing the currents in this figure with those shown in Figure 8-4. If a 3-knot limitation were placed on currents in a one-way canal on Route 10, the gates could be situated at both ends of the canal, about 34 miles apart.

The need to operate the tidal checks at set intervals would require strict navigation rules and convoys of limited length. From an operational standpoint, therefore, it would be desirable to avoid using tidal checks during tidal cycles when current velocities would be acceptably low without them. Although tidal checks are included in canal designs to ensure that current velocities do not exceed 2 knots, navigation in stronger currents would be advantageous.‡ If experience shows that most ships can navigate safely in 4-knot currents, tidal check operation might be suspended. Smaller, more maneuverable ships would transit

*The velocities at the Atlantic end would be minimal because of the small tides there. This contrasts with the unchecked sea-level canal in which maximum tidal currents would occur at the Atlantic end.

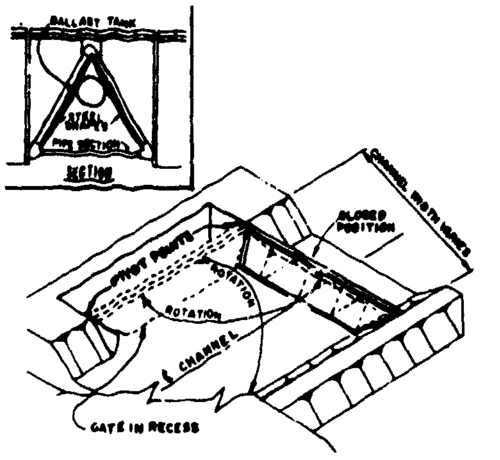
†Two knots has been used as the lower limit of acceptable maximum currents in which large ships can navigate safely. This is based on experience at the Panama Canal where ships have demonstrated a capability to operate in currents up to 2 knots.

‡To facilitate this, gate sills would be installed during initial construction at appropriate locations for 2-, 3-, and 4-knot current limitations.



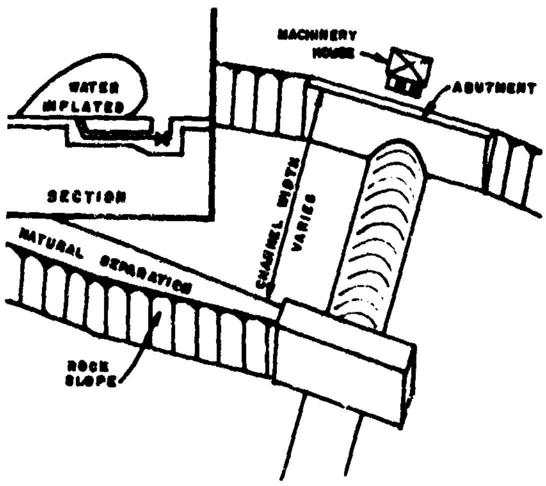
TRIANGULAR ROLLING GATE CONCRETE CURTAIN

Closure made by rolling gate from gate recess or bypass channel, if adjacent, along track installed in gate sill.



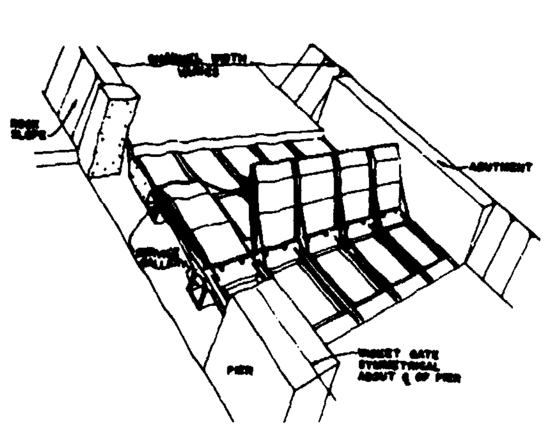
TRIANGULAR ROTATING GATE STRUCTURAL STEEL SHAPES WITH FLOTATION SYSTEM

Location of pivots at ends of gate permit synchronization of closure with tidal currents. Closure is made by positioning gate over either gate sill and lowering by reducing bouyancy.



INFLATABLE DAM GATE

Dam is raised by inflating a flexible fabric gate with water from external pumps.

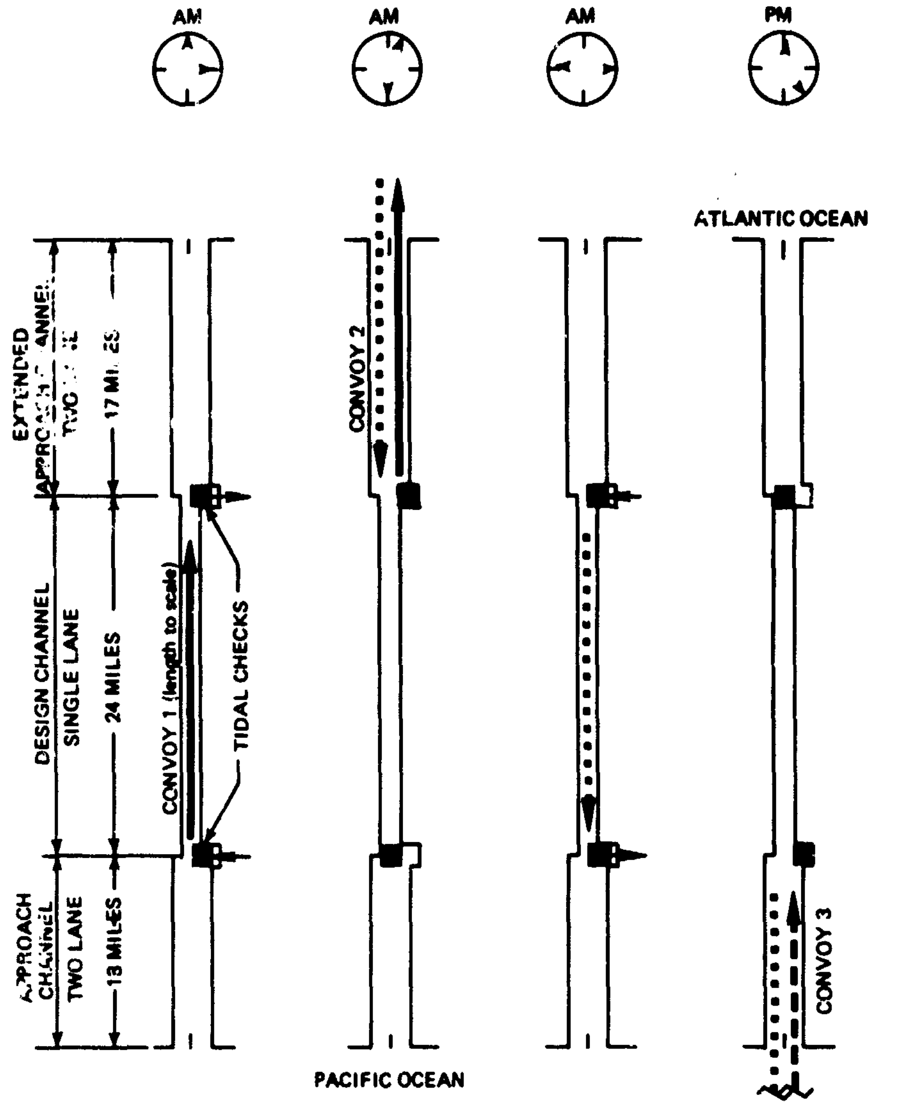


TWO-WAY WICKET GATE

In closure, wicket dams are raised from bottom sill by hydraulic operation of movable support arms.

SCHEMATIC DIAGRAMS OF SOME TIDAL CHECK GATE CONFIGURATIONS

FIGURE 8-7



Step 1
Gates move at mean tide as convoy 1 is between them and moving toward the Atlantic.

Step 2
Convoy 1 has cleared one-way channel and convoy 2 is about to enter it from the Atlantic.

Step 3
Gates move at mean tide as convoy 2 is between them and moving toward the Pacific.

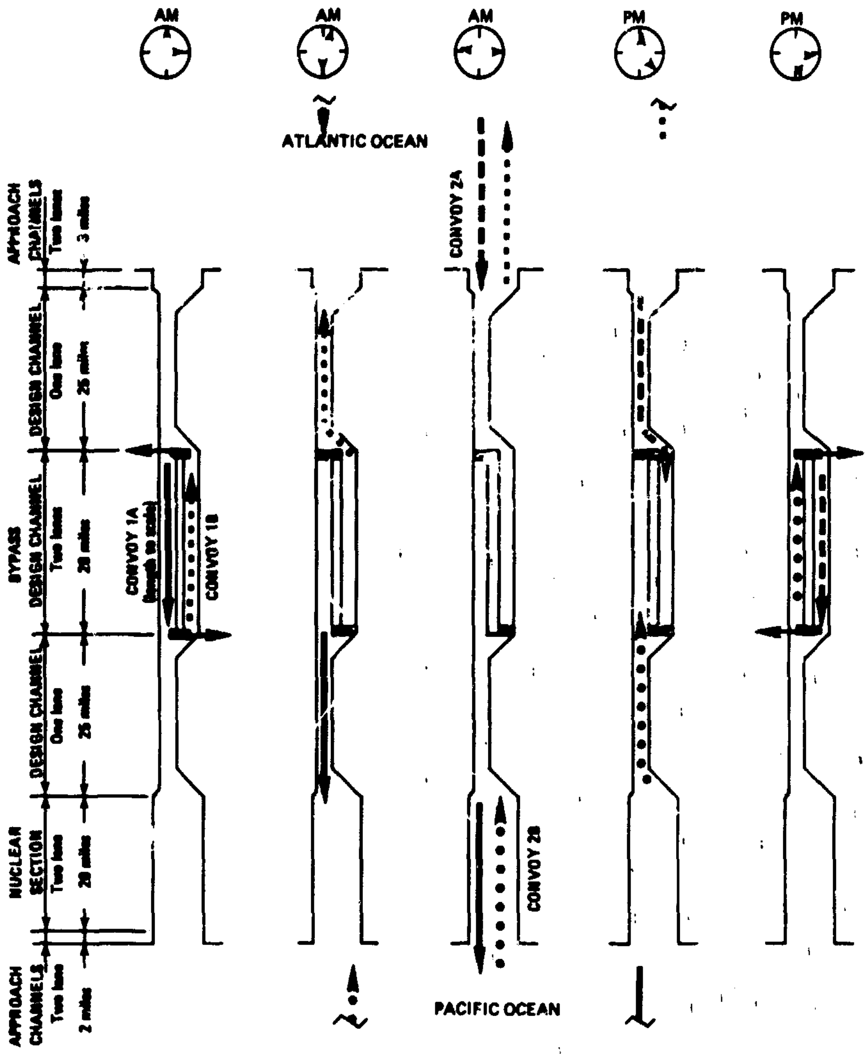
Step 4
Convoy 2 has cleared one-way channel and convoy 3 is about to enter it from the Pacific.

Step 5
Gates move at mean tide as convoy 3 is between them and moving toward the Atlantic.

For control of tidal currents when entire convoy is between gates, tidal checks can be located at the ends of the one-way channel section. The checks would be operated when the Atlantic and Pacific Oceans are at about the same level. As illustrated alternative convoys would transit the design channel in the sequence of tidal check operations presented above.

OPERATION OF TIDAL CHECK GATES AT THE ENDS OF A ONE-WAY RESTRICTED CUT

FIGURE 8-8

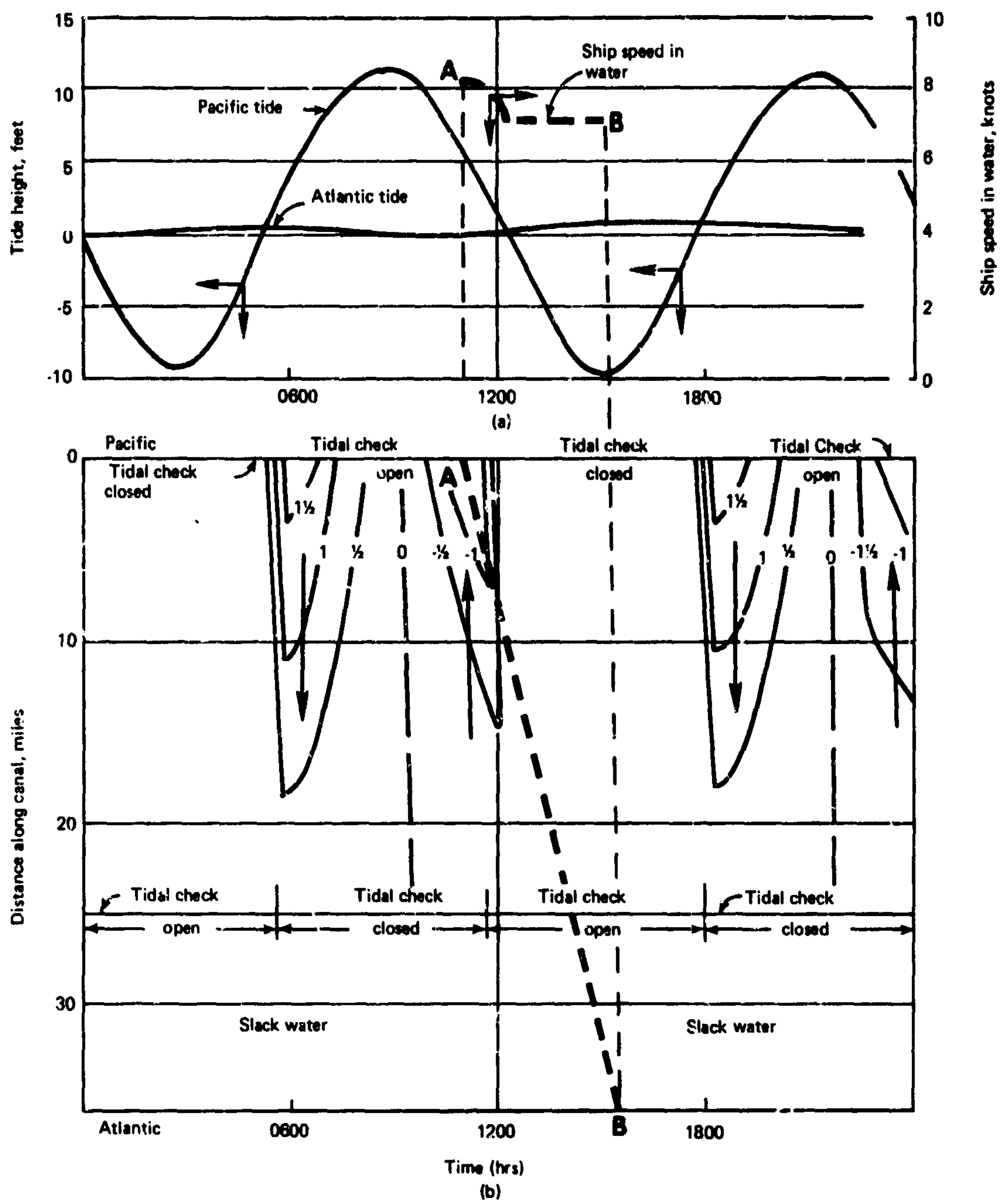


Step 1	Step 2	Step 3	Step 4	Step 5
Convoys 1A and 1B are in the bypass section about to enter the one-lane sections.	Convoys 1A and 1B are in the one-way sections about to enter the two-lane sections at canal ends.	Convoys 1A and 1B are in the two-lane end sections moving seaward. Convoys 2A and 2B are in the two-lane end sections about to enter the one-lane section.	Convoys 2A and 2B are in the one-lane section about to enter the bypass section.	Convoys 2A and 2B are in the bypass section about to enter the one-way sections.

A bypass in the one-way section expedites the movement of traffic. Tidal checks for control of current would be constructed at the ends of the bypass. As in the design one-way configuration, the checks would be operated when the water level in the Pacific is about the same as in the Atlantic. The sequence of traffic movements with tidal check operation are illustrated above.

OPERATION OF TIDAL CHECK GATES AT THE ENDS OF A BYPASS SECTION

FIGURE 8-9



Extreme Pacific tide (a) Resulting currents in a 36-mile design channel on Route 10 with tidal checks (b). Numbered lines show currents in knots, and arrows, direction. Tidal checks shown operating every 6.2 hours in example, but can be operated in multiples of 6.2 hours. Ship enters from Pacific (A) at 1100 hrs in 1.1 kt head current, and reaches Atlantic (B) at 1730 hrs in slack water. Ship speed in water required for a land speed of 7 kts is shown by the dashed line in the top figure.

FIGURE 8-10

without regard to current velocities, while larger ships would transit in favorable currents.*
Environmental considerations, however, might dictate continuous operation of the checks in order to limit transfers of biota between the oceans. (See Chapter 10.)

Ship spacing: A minimum ship spacing of 4 ship lengths measured bow to bow, or 3 lengths clear space between ships, is generally used in confined waterways. In this study, a bow-to-bow spacing of 4 ship lengths has been used for freighters, and 5 lengths for the more massive tankers and bulkers. This results in an overall average spacing of 4.2 ship lengths per ship, or about 2 ships per statute mile of convoy length. This spacing provides sufficient distance for most ships, with the help of tugs, to avoid colliding with the preceding ship should it stop suddenly. Table 8-2 shows that the clear space of 3 ship lengths is adequate for stopping tug-assisted ships of up to about 150,000 dwt in 4-knot following currents. Additional clear space for the occasional ships larger than 150,000 dwt would be provided as required by the current velocities prevailing during transit. This added spacing for very large ships would not significantly affect the average number of ships per mile of convoy.

TABLE 8-2

SUMMARY OF SHIP STOPPING DISTANCES FROM A SPEED OF SEVEN KNOTS RELATIVE TO THE LAND

Ship Size (dwt)	Number of Tugs (3000 hp Each)	Assisted Stopping Distance in 4-Knot Following Current (Ship Lengths)
25,000	1	1.4
50,000	1	2.7
100,000	3	2.1
150,000	3	3.0
200,000	3	3.6
250,000	3	4.2

* Experience indicates that while head currents reduce the stopping distance of ships, the greater speed in water required to maintain constant land speed increases the difficulty of handling large ships in confined waters. Thus, some ships might navigate more readily in a following current, others in a head current.

Canal capacity and operation: Canal capacity would be affected by a number of factors, all of which must be evaluated for each particular canal alternative. These include operational interferences such as bad weather, mechanical failures, dead tows and irregular arrival of ships. Of these, irregular ship arrivals probably would have the greatest influence upon capacity. To provide a basis for comparing the several routes, the average time in canal waters (TICW)* has been limited to 20 hours at the canal's rated capacity. As much as possible, arriving ships would form convoys "on the fly" while still at sea to preclude delays and avoid the difficulties of getting a large number of ships underway from anchorage. The lead ship of each convoy would enter the one-way section of the canal shortly after the last ship of the convoy in the opposite direction leaves it.

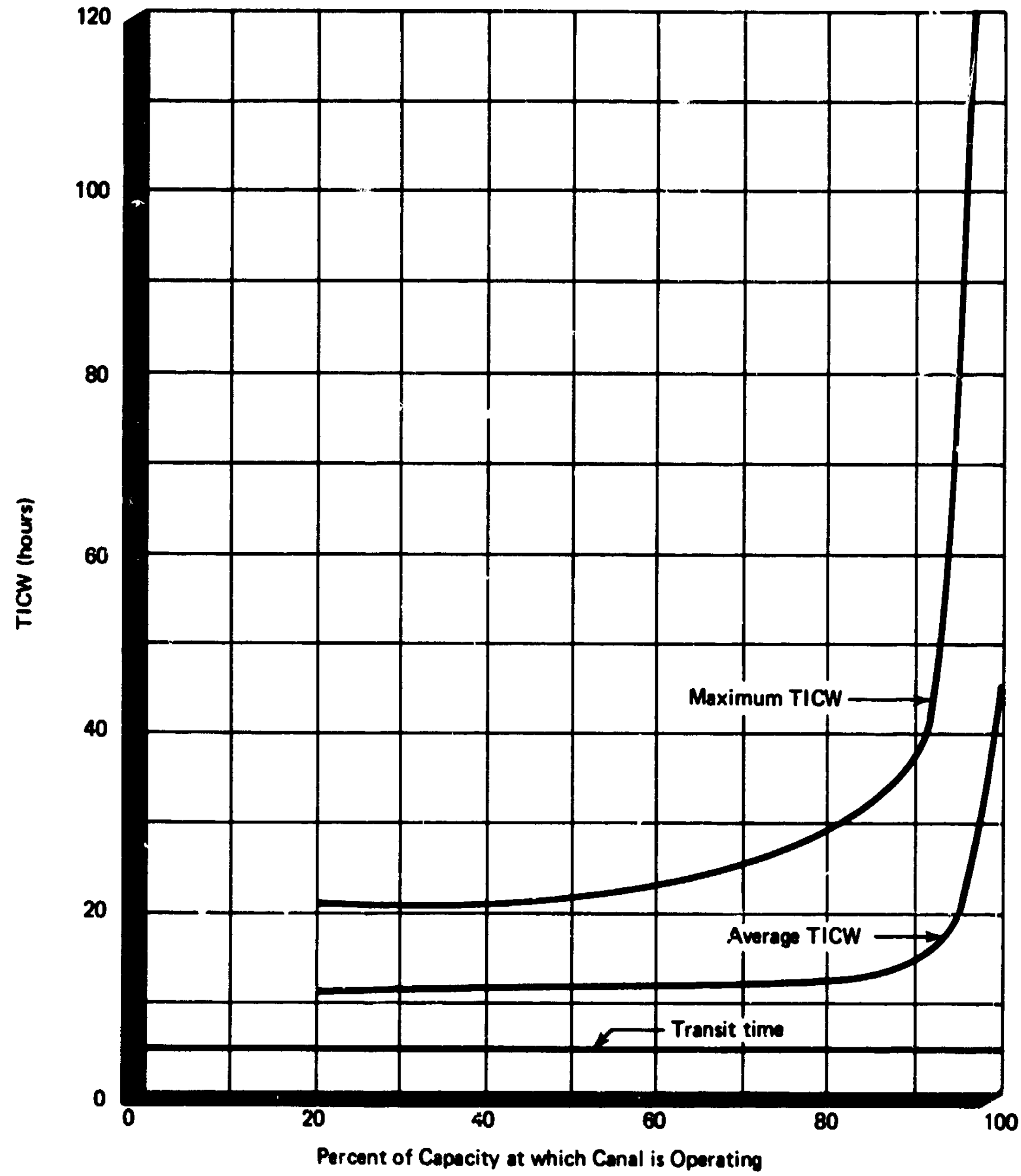
The average TICW is affected only slightly by increases in transits, until transits approach about 90 percent of the canal's capacity, when its TICW rises rapidly.† The 20-hour average TICW selected for capacity comparison occurs at about 90 to 95 percent of capacity for all but a few configurations. Figure 8-11 shows how the average and maximum TICW for Route 10 change as the number of transits increases.

The maximum transit capacity which can be attained with a sea-level canal depends on a balance among four factors: cycle time,‡ canal length, distance between tidal checks, and convoy speed. The use of tidal checks, as previously described, requires that the cycle time have a duration of multiples of 6.2 hours. A 6.2-hour cycle time cannot be used in a 34-mile canal (Route 10), since a one-ship convoy in one direction followed by another in the opposite direction would take about 9 hours just for transiting at a 7-knot land speed. A 12.4-hour cycle would allow 34,000 transits a year in such a canal. Of the 6.2 hours allotted for the convoy to travel in one direction, 4.5 hours would be required by the last ship entering to transit and clear the canal before an opposing convoy could enter it. The remaining 1.7 hours allow a convoy only 13.7 statute miles long, which would not fully utilize the 21 miles maximum allowable convoy length available in the 25 miles between

*TICW is the sum of waiting time and transit time. For purposes of this study, waiting time includes time lost by ships which would have to slow down at sea to enter the canal with a convoy at scheduled times. Transit time includes only the time required to pass through the one-way portion of a canal. Average TICW for the Panama Canal in 1969 during periods when all lock lanes were operational was 18 hours.

†Queuing theory was used to determine the effects of random ship arrival on waiting time.

‡Cycle time is the interval between the entrance of successive convoys traveling in the same direction.



Time in canal waters versus percent of capacity for a 36-mile one-way canal along Route 10. This is based on continuous use of tidal checks, a 12.4 hour cycle time, seven knots average land speed and a 15 minute interval between the last ship of one convoy clearing the one-way channel entrance and the entry of the lead ship of the next convoy.

FIGURE 8-11

tidal checks.* Convoys 21 miles long can, however, be used with a cycle time of 18.6 hours. In this cycle the Pacific gate would be closed continuously for 12.4 hours after which it would be open for 6.2 hours. The Atlantic gate would be closed during the 6.2 hours when the Pacific gate is open. The increase in convoy length more than offsets the decrease in the number of convoys possible, and capacity increases to 38,000 transits a year. A further increase in cycle time serves only to decrease the number of convoys without a corresponding increase in convoy length; it results in lower transit capacities. In the configuration discussed above, a 7-knot land speed is compatible with the 25-mile tidal check spacing selected to limit currents to less than two knots. This permits the last ship in one convoy and the first ship in the second convoy to traverse the 25-mile distance, with allowances for safe operation, in the 6.2-hour interval in which the tidal checks can be moved without wasting available convoy space.

Variations in tide levels associated with the lunar cycle periodically cause conditions during which currents may remain low enough to permit transiting without gates. At such times, only the very largest transiting ships would be tied to tidal cycles, and the choice of cycle time would become arbitrary. Transits could increase during these periods, with ship arrivals scheduled well in advance to take maximum advantage of opportunities for increasing the number of ships accommodated.

Lengthening the distance between tidal gates tends to provide an increase in transiting capacity by allowing longer convoys, but this results in higher peak currents. A practical limit on this distance is also imposed by the land speed of the ships, i.e., they must be able to travel the appropriate distance in time to meet the schedule of gate movement.

In a bypass configuration, convoys entering opposite ends of the canal would be scheduled to pass each other in the divided section (See Figure 8-9). When these convoys have cleared the canal, the operation would be repeated. In a canal without tidal checks, the main advantage of a bypass is that it permits a short cycle time at low traffic levels. Its disadvantages lie in limitations it imposes on convoy lengths, the more rigid traffic control it requires, and its inability to accommodate variations in cycle time under conditions of fixed land speed. The effect of a bypass on transit capacity depends on the length of the canal and the length and location of its bypass. At least one bypass would be necessary to obtain 35,000 annual transits in any single-lane canal longer than 50 miles. In shorter canals a centrally located bypass would reduce TICW significantly until transit growth is constrained by the short maximum length.† In this case, operating the canal without using the bypass may allow more transits.‡ If tidal checks must be used, a bypass not only reduces TICW but increases capacity also. Table 8-3 compares the effects of tidal checks on capacity of Route 10 in configurations with and without a bypass.

*This provides 2 miles clearance at either end of the convoy to allow time for shifting of the gates without stopping the convoy.

†The convoy length would grow with increasing traffic. Its maximum length would approach the length of the bypass section.

‡A bypass also would provide a significant part of the canal length required for expansion to two one-way lanes should that become necessary as a means of providing additional capacity.

Automated traffic control: Even the largest ships are subject to so few restrictions while at sea that no special operating procedures are required. Within the confines of a sea-level canal, however, systematic automated control of both ships and canal operations would be necessary. In addition to providing operational data on every ship, and on the changing tides and weather conditions, such a system would assign vessels to their positions in convoys, and schedule convoys several days in advance to ensure efficient operations. Similar concepts are used in air traffic control and in controlling traffic on the St. Lawrence Seaway. A measure of the need for automated control is apparent when it is realized that to transit 60,000 ships per year without tidal checks would require the daily formation of two convoys, each over 40 miles long and containing over 80 ships. Operation with tidal checks would involve smaller convoys but more rigid control.

TABLE 8-3

TRANSIT CAPACITIES OF A SEA-LEVEL CANAL ALONG ROUTE 10 WITH AND WITHOUT A 14-MILE CENTRALLY LOCATED BYPASS AND WITH 20-HOUR AVERAGE TIME IN CANAL WATERS

	Tidal Checks Located for Maximum Currents of		
	2 knots[a]	3 knots[a]	4 knots[a]
Without	38,000 (100%)	45,000 (90%)	66,000 (26%)
With	56,000 (100%)	56,000 (100%)	57,000 (78%)[b]

[a]Tidal check gates operate when necessary to maintain current velocities below this acceptable value. Figures in parentheses show the percent of tidal cycles during which tidal checks must be used to limit the canal currents to the values shown.

[b]This indicates that if operation in currents up to 4 knots is acceptable, there is no advantage to a bypass on this route.

Other design factors: For the routes investigated in this study and the size of channels involved, project cost is relatively insensitive to such criteria as minimum radius of canal curves, minimum distance between curves, and maximum angle of turn. Accordingly, the plans and estimates of this study are based upon criteria which are more favorable to navigation than those of most of the world's waterways.

A ship in motion generates a characteristic pattern of waves. This pattern changes when the ship moves from deep to shallow water and into the confined reaches of a canal. Much of the ship's power is lost in making waves, thus reducing its attainable speed. Hydraulic

model tests of ships in canals, including those undertaken for the Commission, have reproduced the wave systems generated by ships in confined waters. These tests showed that while waves tend to reduce ship speed, they could be tolerated by adequately powered ships operating in the design channel.

Waves caused by ships moving in restricted waters can cause damage to unprotected shore installations and canal banks of soft materials. At the Suez Canal, for example, considerable construction has been undertaken to protect the sandy banks from wave wash. Bank protection would be provided for the isthmian sea-level canal in reaches where bank materials are susceptible to erosion.

Increasing capacity at minimum cost: The canal designs proposed in this study were based on conservative navigation criteria. It is likely that continued research and experience would demonstrate that these criteria could be relaxed. This could lead to either a less expensive canal or a greater throughput with the present design. Some of the measures affecting navigation which should be considered in the final design and in the operational phase are:

- Operating in faster currents. This would serve to increase capacity, particularly if continuous operation of tidal checks were not necessary.
- Operating without tidal checks. This would permit much greater flexibility in scheduling, thus reducing waiting time and increasing capacity, but it would only be effective if operation in currents above 4 knots were shown to be practical.
- Operating at land speed above 7 knots. This would increase capacity with or without tidal checks, if ship spacing did not have to increase commensurately.
- Constructing a small bypass. Expansion plans call for the bypass channel to be the same size as the design channel. It could be constructed with a channel of about 450- by 50-feet, which would accommodate most of the ships desiring transit. Large ships would use only the main channel; the smaller ships could use either leg. (On Route 10 the cost difference between a bypass excavated to design channel dimensions and one 450- by 50-feet is about $140 million.)
- Developing passing procedures so that smaller ships could transit the restricted section in a two-way mode.

CHAPTER 9

COST ELEMENTS

In general, throughout this study, construction cost estimates include the cost of all work necessary for complete facilities, ready for operation and meeting all project requirements. Operation and maintenance cost estimates, including plant replacement costs, also have been developed and are shown separately. Interest and amortization are not included in either of these cost categories; they are discussed in Annex III, *Study of Canal Finance*.

Because of the project's size, estimates included in this study are more fully developed than those of most engineering feasibility studies. Excavation quantities have been estimated from preliminary design drawings and maps reflecting the best available data and information. Unit prices include allowances for minor items not estimated separately. Since channel excavation would be the principal cost element, excavation systems have been developed in detail and costed to include a breakdown of plant, labor, and other charges. Contingencies and costs for engineering, design, supervision, and administration are included as separate items. All costs are in terms of December 1970 dollars.* The Chief of Engineers will maintain records for updating these cost estimates, if necessary.

Construction costs: Costs included in the estimates in this Annex have been limited to those directly associated with the design and construction of an isthmian canal. Principal cost elements are:

- Construction items such as clearing, relocation, excavation, evacuation of the nuclear exclusion areas, flood control, harbors, highways, operating facilities, health and sanitation, and support facilities for construction and transit operation.
- Contingency factors which are applied to the construction items' cost to meet unforeseen conditions. Contingency allowances normally used in engineering feasibility studies range from 15 to 25 percent. Reflecting the degree of refinement to which analyses of the several alternatives have been carried, allowances for

*In keeping with the usual government practice for water resources projects, no allowance has been made for inflation. This policy stems from the belief that inflation affects both costs and benefits of projects to approximately the same degree, and that the estimation of a reliable factor for inflation over the lifetime of a large construction project is impractical.

contingencies for each major feature considered by this study were made in accordance with the following schedule:

Type of construction	Percent of itemized costs
Conventional excavation	10*†
Conventional construction, other than excavation	20†
Nuclear construction, less supporting work	30‡

- Engineering and overhead costs involved in planning, managing and supervising the construction effort. These are added to the base construction costs and include such items as collection of topographic, meteorologic, hydrologic, and geologic data; testing foundation material; preparation of engineering reports and design memoranda; development of plans, specifications, and cost estimates; supervision and inspection of construction; and overhead costs of managing and supervising the project. For the purposes of the feasibility study, these costs were taken as 7 percent of the total estimated base construction costs, including contingencies.

Operation and maintenance costs: Operation and maintenance costs are those continuing costs incurred in the operation and maintenance of the facilities directly involved in the operation of the canal. Although the canal operating organization may engage in other activities, no attempt has been made to estimate their extent.

*The Technical Associates have recommended that estimates of conventional excavation volumes be presented as ranges based on available knowledge of geological conditions:

	Ranges with respect to computed volume
Routes remote from the Panama Canal	+30 to -10 percent
Routes proximate to the Panama Canal	+20 to - 5 percent

In their opinion, total quantities excavated would be within these ranges which provide for possible future changes in the understanding of the site geology and slope stability. These ranges have been considered in estimating costs of the conventional routes and in making comparisons between routes; however, for convenience and to conform with normal procedures, only the base estimates are presented herein.[37]

†Initial estimates for the routes showed that contingency costs for all conventional construction, including excavation, averaged about 12% of the base cost of these items. Consequently, 12% was used as the contingency factor for all construction costs except those for nuclear operations.

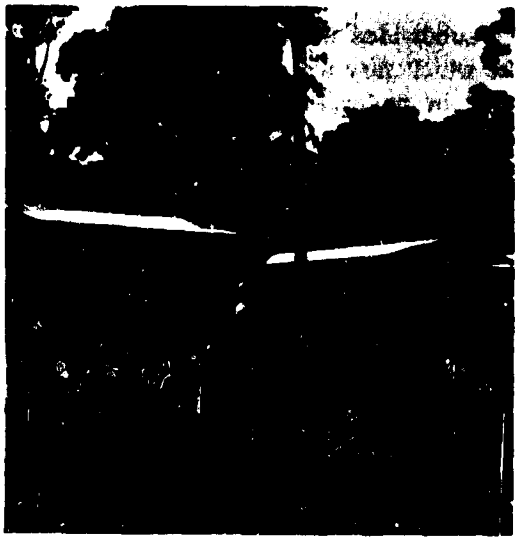
‡The AEC does not believe that a blanket contingency of 30 percent to nuclear construction is desirable, as the uncertainties surrounding nuclear excavation do not lie in the cost of nuclear explosives or explosive related field operations. Such uncertainties lie in the area of providing a useful channel without substantial modification by conventional means. Consultants and advisors to the Engineering Agent, citing the lack of experience in multiple cratering, recommended contingency factors in the range of 50 to 100 percent. In light of these considerations, the Engineering Agent selected 30 percent as an appropriate contingency factor to be applied across-the-board to cost estimates for nuclear construction in this study.

Operation and maintenance costs have been subdivided into those which vary only slightly from year to year (fixed costs), and those which vary with the number of transits (variable costs). Because many of the routes lie in undeveloped areas, the operating organization would have to provide essential supporting services for project personnel, as well as perform the normal functions of administration, waterway operation, and maintenance. Supporting services for ships would include traffic control centers, aids-to-navigation, communications, maintenance equipment, and the provision of marine pilots and tugs. Maximum dependence would be placed on the private economic sector of the host country to provide ancillary supporting services. A reliable adequate water supply would be an important consideration in a lock canal. Some costs would be relatively constant over a wide range of transit levels, while other costs, such as those for marine pilots, would vary almost directly with the number of transits. The total operation and maintenance cost would be the sum of the fixed costs, the variable costs, and the costs of major replacements. Thus, as the number of transits increases and more ships share the fixed costs, the cost per transit decreases. Operation and maintenance costs are strongly dependent upon the length of the canal.

Real estate costs: Cost estimate totals shown in this study do not include land acquisition costs, since royalties based on a rate per ton of transited cargo are expected to constitute the entire reimbursement to the host country. However, the value of all real estate required for the project has been estimated according to the following criteria:

- Fee title for the canal and adjacent land for permanent facilities;
- Permanent easements for access roads and for land that may be occasionally inundated; and
- Temporary easements for spoil areas and other areas needed only during construction.

Other costs: Not included in this study are first costs for defense facilities and support facilities not related to transit operations; treaty costs including acquisition of land and improvements, and resettlement other than evacuation; interest on capital investments, and intangible costs for indirect effects and their economic impact.



Wooden huts, such as these at Curiche, were constructed at the main base camps.

The barge shown here was used as a floating base camp on the Atrato River since there was very little solid ground in the area for establishing land-based camps.

Temporary camps, such as this one near Morti on Route 17, were set up to support data collection parties operating out of the base camps.

Camp facilities were chosen to fit the local environment and the length of time they would be needed.

CHAPTER 10

ENVIRONMENTAL ASPECTS

Initially, emphasis was placed upon terrestrial and marine bioenvironmental investigations conducted to assess the possible transfer of radionuclides to man through various food chains. Simulation techniques were developed to predict the canal's modification of certain environmental parameters, particularly the redistribution of radionuclides. As the study progressed, emphasis shifted to the probable effects of biotic interchange between the oceans. A tabulation of studies sponsored by the Commission and relevant to environmental concerns is given in Table 10-1.

As a result of these studies and other pertinent investigations, certain general evaluations of the major environmental effects of building a sea-level canal can be made in terms of:

- Damage to living resources from various types of excavation;
- Dispersal and biological transfer of radionuclides from nuclear excavation;
- Potential physical and genetic damage to biota from radiation;
- Biotic interchange between the Pacific Ocean and the Caribbean Sea through a sea-level canal;
- Ecological changes in Gatun Lake caused by increased salinity if the lockage water is augmented by pumped seawater; and,
- Modification of the Atrato wetlands with resultant effects on the estuaries of Candelaria and Colombia Bays.

The outcomes of such complex situations are not yet known. Nevertheless, the Commission's investigations have been carried to a point where preliminary judgments can be made on the necessity and feasibility of countermeasures, the acceptability of risk that might be involved, the possible penalties for accepting damages, and the need for additional studies.[38,39]

Environmental effects of excavation and spoil disposal: Regardless of the method employed for its excavation, construction of a sea-level canal would require the disposal of immense quantities of spoil. It would be necessary, therefore, to place this material so as to avoid adverse environmental consequences. Typical of problems of this nature that might be encountered is the disposal of spoil in Gatun Lake. If material removed by conventional cut-and-haul methods were placed there, it would alter the lake's characteristics. As it

TABLE 10-1

PRINCIPAL ENVIRONMENTAL STUDIES

Subject Area	Investigating Agency	Research Results
Terrestrial and marine environment	Battelle Memorial Institute, Columbus, Ohio	Planned, managed, and reported on overall bioenvironmental investigations required for nuclear safety feasibility study.
Human ecology in Panama	Dr. R. Torres de Arauz, Panama, Republic of Panama	Obtained demographic data on human population groups in Darien Province, Panama.
Human ecology in Colombia	Ecuadorian Institute of Anthropology and Geography, Quito, Ecuador	Obtained demographic data on human population groups in Choco Province, Colombia.
Agricultural ecology	University of Florida, Gainesville, Florida	Obtained data on the agriculture in the regions around Routes 17 and 25, including elemental analysis of samples.
Terrestrial ecology	University of Georgia, Athens, Georgia	Described and classified terrestrial ecosystems in regions of Routes 17 and 25 and estimated transfer of radionuclides among ecosystems.
Freshwater ecology	Battelle Memorial Institute, Richland, Washington	Collected data; evaluated and predicted potential radiation exposure through freshwater systems in regions of Routes 17 and 25.
Estuarine and marine ecology	Puerto Rico Nuclear Center, Mayaguez, Puerto Rico	Collected data; evaluated and predicted potential radiation exposure through marine food chains in regions of Routes 17 and 25.
Marine resources	University of Miami, Miami, Florida	Reviewed and collated data on marine environment in Isthmian region, with emphasis on commercial fisheries.
Hydrologic redistribution of radionuclides	Hazelton-Nuclear Science Corp., Palo Alto, Calif.	Prepared model for estimating hydrologic redistribution of radionuclides in the vicinity of Routes 17 and 25.
Radionuclide redistribution in tropical rainforests	Puerto Rico Nuclear Center, San Juan, Puerto Rico	Determined behavior of radionuclides in experimental tropical forest to compare with forest areas in the vicinity of Routes 17 and 25.

TABLE 10-1

PRINCIPAL ENVIRONMENTAL STUDIES (Cont'd)

Subject Area	Investigating Agency	Research Results
Radioactivity dose estimation	Oak Ridge National Laboratory, Oak Ridge, Tennessee	Estimated doses to individuals or population groups in vicinity of routes investigated for nuclear excavation.
Marine organisms	University of Miami, Miami, Florida	Provided geographical distribution data on marine organisms to assist in evaluating effects of biota mixing.
Effects on marine ecology	Battelle Memorial Institute, Columbus, Ohio	Estimated possible effects of intermixing marine biota from the Pacific Ocean and the Caribbean Sea.
Medico-ecology studies, Routes 10, 14, 17, and 25.	Office of the Surgeon General, U.S. Army	Compiled data on diseases, vectors, and health conditions that would be encountered in construction on canal routes.
Numerical computations of tital currents in the proposed sea-level canal	Massachusetts Institute of Technology, Cambridge, Massachusetts	Estimated the currents and net flow of water from the Pacific to the Atlantic for various sea-level canals.
Marine ecological research program	National Academy of Sciences/National Research Council	Proposed future program for ecological research, emphasizing mixing of marine biota.

became shallower, environmental changes inevitably would occur, followed by a change in its ecological balance.

If spoil were placed in adjacent valleys or other low elevations, the vegetation and animal life of that and adjoining areas would be affected. Construction of access roads and other support facilities also would modify the ecology of the region. The rate of biotic redevelopment, which generally is rapid in tropical environments, would depend on the fertility and diversity of the spoil Alluvium, muck, and weathered rock would be particularly conducive to rapid regrowth. Igneous material from deep excavations would weather slowly, requiring the passage of several years before plant communities could be established upon it. Because of differences in geologic origin of spoil, as well as differences in regional and internal drainage, parent material weathering history, and successional

status,* the returning plant and animal communities might differ from the original occupants of the area.

Most excavated material would be removed from depths at which tropical leaching processes have not operated to deplete its fertility. Properly placed with adequate drainage, this spoil soon should be suitable for farming, furthering governmental efforts to place more people on the land. Comparable opportunities might be available from dredged materials.

Nuclear safety studies conducted for the Commission have shown that hazards to human populations living near the nuclear alinements could be minimized by using improved explosives and emplacement techniques and by temporarily evacuating residents from specified exclusion areas. An area 15 to 20 miles wide and 20 to 25 miles long would be subjected to substantial airblast and ground shock from each nuclear cratering detonation. An even greater area would be subjected to radioactive fallout and resultant potential biological damage. The possibility of genetic alteration of local members of plant and animal species from canal excavation is difficult to assess. Although not considered likely to be serious, changes of this type remain an area of concern, requiring continued study.

Plant and animal populations of the area would be harmed by soil and rock ejected from the cut, as well as by radiation. Ejecta would range in depth from several hundred feet at the lips of the cut to a few inches at distances of several thousand feet from the canal, killing most life forms in the area so covered.

Although the territory affected by spoil disposal, radioactivity, or ejecta deposition would be extensive, it would be small compared to the entire region having similar biotic composition. Lasting adverse environmental consequences of the excavation process are not expected to be significant.

Ecological transfer of radionuclides: Detailed bioenvironmental studies were conducted in the regions of Routes 17 and 25 as part of the overall nuclear safety investigations. These studies were directed primarily at the evaluation of the potential exposure of people to radiation. Should nuclear excavation be employed, some radionuclides would be introduced into aquatic and terrestrial ecosystems, and ultimately would appear in fish, birds, and other animals, including man. With proper precautions, human exposure to radionuclides transmitted by food chains could be controlled effectively. A small possibility remains, however, that biologic accumulations and concentrations of harmful radionuclides could occur in areas remote from the construction site. Danger to humans from such a possibility would be avoided by radiologic surveys of organisms in which radionuclides are likely to concentrate. The studies that have been conducted to date lead to the belief that biologic concentrations of radioactivity at levels that would endanger humans would not be likely to result from nuclear excavation along any of the canal routes considered.

While primary attention was focused on cultivated crops, plants, and animals in food chains leading to man, broader ecological studies also were made. Numerous biotic samples were collected and analyzed to characterize general ecological systems, and to evaluate the food chain transport of radionuclides. In addition to detailed studies of terrestrial and

*Relative developmental stage of plant and animal communities along semi-predictable lines of replacement tending toward ecological stability.

freshwater ecosystems, marine and estuarine physicochemical and ecological studies were carried out at a number of stations along the Pacific and Caribbean coastlines. These field investigations included chemical analyses of water and organisms, and diffusion studies at various offshore locations to estimate potential movements of radionuclides.

Biotic interchange: An unobstructed sea-level canal across Central America would allow relatively easy passage of marine organisms. Certain forms of marine life now pass through the Panama Canal even though Gatun Lake provides a highly effective biotic barrier. Barnacles and other immobile organisms are carried through on the hulls of ships, and some small plants and animals survive in ballast water carried from one ocean to the other. Linking the oceans with an unobstructed salt water channel would greatly facilitate the movement of these and other organisms.

The net flow of water from Pacific to Atlantic would depend upon the size, length, location, and configuration of the canal. This flow would average as much as 100,000 cubic feet per second in a relatively short unrestricted canal (Route 17); on the other hand, a freely floating object would take as long as ten days to move from the Pacific to the Atlantic through a 100-mile unrestricted canal on Route 25. The use of tidal check gates would reduce flows greatly. Proper timing of gate movements could reduce the net flow to zero, although there would be some mixing through the open gates, similar to the mixing and flushing action in any tidal estuary.

Pacific water, though slightly cooler than that of the Caribbean, has about the same salinity. Periodic tidal flow in a salt-water connection would aid the movement of free-swimming species and the passive transport of small organisms from one ocean to the other. A canal would also provide transitional habitats where organisms could be harbored pending their adaptation and dispersal. Conversely, the planned use of tidal gates and the sedimentation, turbulence, and freshwater inflow of a sea-level canal would serve to restrict the extent of any migrations.

Taxonomic studies indicate that the Atlantic and Pacific ocean species along the Isthmus are closely related, even though few are identical. This similarity results from the linking of the Atlantic and Pacific Oceans until recent geologic time, perhaps 3 million years ago. When such closely related species are allowed to intermingle, several results may occur. Concern has been expressed about three potentially undesirable biologic consequences of such intermingling through a sea-level canal:

- Some invading organisms might be so highly successful in their new environment that they could disrupt the previous ecological balance and become pests.
- Successful migrants through the canal could carry parasitic organisms for which defense mechanisms do not exist in the new environment. Although such a possibility cannot be dismissed entirely, experience in other similar areas leads to the belief that it is unlikely to be a significant threat. In past geologic eras, marine fauna of the isthmian region were free to interact. Their subsequent separation by the isthmus, while permitting and creating different ecosystems in the two oceans, probably has not significantly affected the internal environment of the host fauna for the parasite. Thus, migrant parasites are expected to be less harmful than totally alien organisms

– Pairs from similar species might interbreed freely but produce infertile offspring. Under certain possible, but extremely unlikely conditions, this could lead ultimately to the extinction of both species. The few aquarium breeding experiments carried out so far on related Atlantic and Pacific fish species are inconclusive. Since many species pairs have not yet been tested, the possibility of extinction of some species cannot be eliminated.

The situation most nearly comparable to an American Isthmian sea-level canal is the biotic passage created a century ago when the Suez Canal was built, linking the Red Sea and the Mediterranean. (Aquatic plants and animals around Suez are not so closely related as are those of Panama; and the Mediterranean Sea has a less richly endowed biotic assemblage than the Red Sea.) At least 150 species of plants and animals occurring in the eastern Mediterranean have emigrated with the prevailing flow from the Red Sea through the Suez Canal; only a very few have moved in the opposite direction. Of the 24 Red Sea fish species that have moved into the Mediterranean, 11 are now commercially important. There is no evidence of long-term adverse effects of this interchange.

The likelihood of the successful establishment of alien biota in the ecosystems of the Caribbean or Pacific is a subject of debate not capable of being finally resolved within the present state of knowledge. However, should future research indicate the need for a biotic barrier across the canal in addition to tidal check gates, salinity or temperature barriers or other bio-regulators could be installed. Such barriers were not included in conceptual designs because the need for using them in addition to tidal checks has not been established. As they are presently understood, these barriers appear to be technically feasible, although their operating costs could be extremely high. Admitting fresh water into the canal between the tidal checks has been proposed. It would come from streams which otherwise would be diverted. Proposals also have been made for raising the water's temperature, using waste heat from power plants. The combination of heating and dilution should be more effective than either acting alone. In any case, the success of any method adopted would depend on the effectiveness of the tidal gates in restricting flows, since heating or diluting an unobstructed interoceanic canal sufficiently to establish an effective biotic barrier appears economically infeasible at this time. Other methods such as bubble screens, sonic barriers and electric and magnetic fields have been suggested and may merit investigation in the future.

The ecological consequences of the movement of marine organisms are unknown at the present time. Marine biologists are not in full agreement on this subject; their predictions range from disaster to possibly beneficial results. All share the belief that further research is needed. Because of this divergence of views, the Commission engaged Battelle Memorial Institute to study the problem. A summary of its report[38] is at Inclosure D. Its principal findings were:

– No firm evidence has been found to support any predictions of massive migrations from one ocean to another, followed by widespread competition and extinction of large numbers of species.

– Differences in environmental conditions on the two sides of the isthmus and the prior occupancy of similar niches by related or analagous species constitute

significant deterrents to the establishment of those species which may manage to get through a canal.

- The Pacific species most likely to become established along the Caribbean shore are those of estuarine and other shallow water habitats.
- Improvements in the precision and reliability of ecological predictions would require a comprehensive long-term program of well-coordinated studies in physical oceanography, marine ecology and basic biology in the seas and estuaries adjacent to the isthmus.

Regardless of how the question of harm from biotic mixing may eventually be resolved, there is general agreement that the estuaries at either end of a sea-level canal would be altered considerably. There would be silting, diverted currents, and turbulence created by ships. Breakwaters and jetties built to provide protection for ships and to reduce maintenance dredging would also inhibit littoral drift. Near-shore biota would be affected strongly by these changes and some might not adapt. The great length of shoreline available, however, suggests that no species would be threatened with extinction. The greatest impact would be felt in the Atrato estuary; yet even there, the vast extent of the estuary provides assurance that its environmental values would not be destroyed by a canal.

It appears that, for the most part, the ecological impact of sea-level canal construction on its local area would be minor in magnitude and extent. The great expanse of undeveloped land, the abundance of tropical life, and the hot, humid climate would tend to overwhelm terrestrial ecological disturbances in short order. A major possible exception is the effect of opening up of a passageway which would allow marine life access between the oceans. The possibility of dire consequences has been raised but not proven. Limited study indicates that risks are small; however, many experts disagree. More study is required.

Gatun Lake: Lockage water supply limits the Panama Canal's ultimate capacity. It is possible to increase available supplies by pumping seawater into Gatun Lake. If this were done, and lockage water could not be recycled, Gatun Lake would tend to become brackish and some existing plant and animal spe[illegible] might disappear. Additionally, a variety of estuarine organisms adapted to low sa[illegible] [illegible]ight become established. Ecological surveys conducted for the Commission identified many species of fish occupying near-shore marine habitats and extending their ranges up freshwater rivers. These and other organisms would be candidates for establishment in the lake.

The Atrato lowlands: The construction of the canal, diversion channels and spoil disposal in the Atrato flood plains in northwestern Colombia would be expected to produce significant changes in the ecology of the flood plain and associated estuaries. Extensive diversion channels on both sides of the canal would be excavated to accommodate the flows of the Salaqui, Cacarica and Atrato Rivers. Spoil disposal in the area would be behind levees and would raise periodically flooded areas several feet above sea level. The high organic content of the hydraulic spoil would aid its rapid revegetation to brush and small trees or its conversion to agricultural uses.

The extensive water diversions, flood control and filled land would alter the hydrologic and physical characteristics of much of the Atrato estuary. Changes in the frequency, depth

and duration of flooding would alter (probably reduce) the nutrient and biotic contribution of the wetlands to the coastal region. Flora and fauna dependent on these supplies would be affected.

PART III – EVALUATION OF ROUTES

Salient features of eight potentially feasible routes were examined to select those which, from an engineering standpoint, are the most promising. Conceptual designs and detailed cost estimates for the routes thus selected are included in Part IV.

Cost estimates have been based on specified methods of excavation. The methods chosen were considered to be the least costly for each route. The adoption of any particular method does not imply that other methods would not be equally practicable.

Although the quality of data varies widely between routes, it is adequate to permit a comparison of their feasibility and costs.

CHAPTER 11

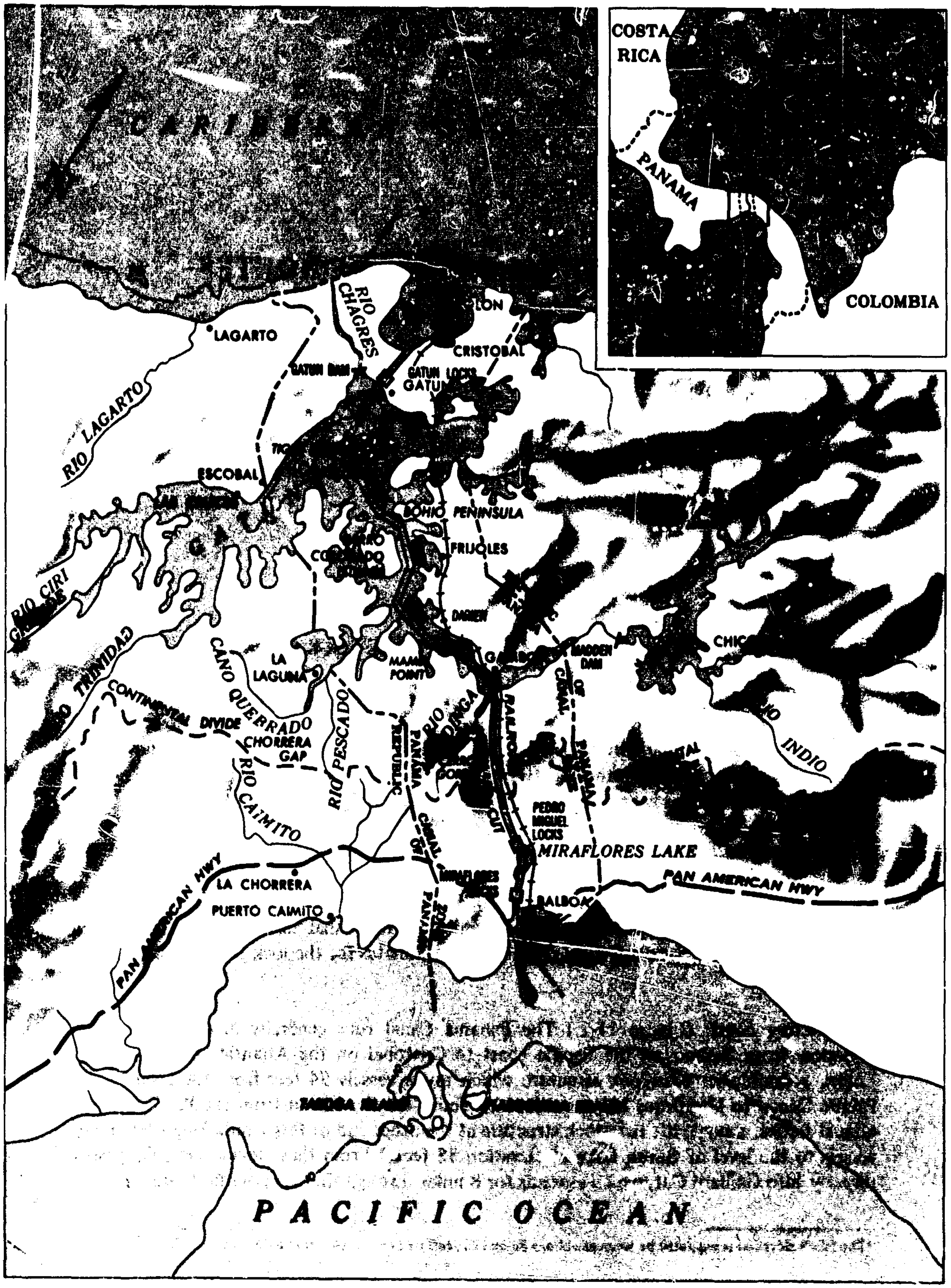
ROUTE 15 – PANAMA CANAL ZONE LOCK CANAL

Route 15, an improved lock canal route along the alinement of the Panama Canal, was considered for the sole purpose of establishing a standard against which the various sea-level alternatives could be measured. Several lock canal plans which have been proposed for modernizing and expanding the existing canal are described in this chapter. A detailed discussion of these plans is presented in Appendix 9.

Accuracy of estimates: The data available for an engineering feasibility study of the various Route 15 proposals are excellent. The climatic, hydrologic, and geologic records of the Canal Zone area extend back nearly 100 years. Exploration and excavation done in connection with maintenance and cut widening of the canal have resulted in detailed geologic data along its most critical reaches. Cost estimates for the lock canal are considered to be reliable.

Existing canal: (Figure 11-1.) The Panama Canal runs generally in a northwesterly direction from Balboa on the Pacific coast to Cristobal on the Atlantic. The Miraflores Locks, a double-lift twin-lock structure which raises vessels 54 feet from the level of the Pacific Ocean to Miraflores Lake, are located about 6 miles inland from the Pacific. Pedro Miguel Locks, a single-lift twin-lock structure at the other end of this 1-mile-long lake, raise vessels to the level of Gatun Lake at elevation 85 feet.* From these locks the canal passes directly into Gaillard Cut, which extends for 8 miles through the Continental Divide. For 23

*The lake's elevation is regulated between elevations 82 and 87 feet. Its nominal elevation is 85 feet.



PANAMA CANAL
THE CANAL ZONE AND VICINITY

SCALE IN MILES
5 0 5 10
DEPTH IN FATHOMS

FIGURE 11-1

miles from the cut's north end near Gamboa, the canal follows an irregular course through Gatun Lake to avoid islands and peninsulas. At the north end of the lake are the Gatun Locks, triple-lift twin-locks which lower vessels to sea level about 2 miles inland from Limon Bay. The total length of the Panama Canal, including approaches, is 48 miles.* The 12 lock chambers are 1,000 feet long, 110 feet wide and have limiting depths of 40 feet over the sills. The minimum navigation prism is 500 feet wide by 42 feet deep, with about 3 additional feet of overdepth. The existing facilities accommodate ships up to about 65,000 dwt. In Fiscal Year 1970 the Panama Canal transited 15,523 large ships. A program of improvements by the Panama Canal Company is expected to increase the transit capacity to 26,800 ships per year when required.

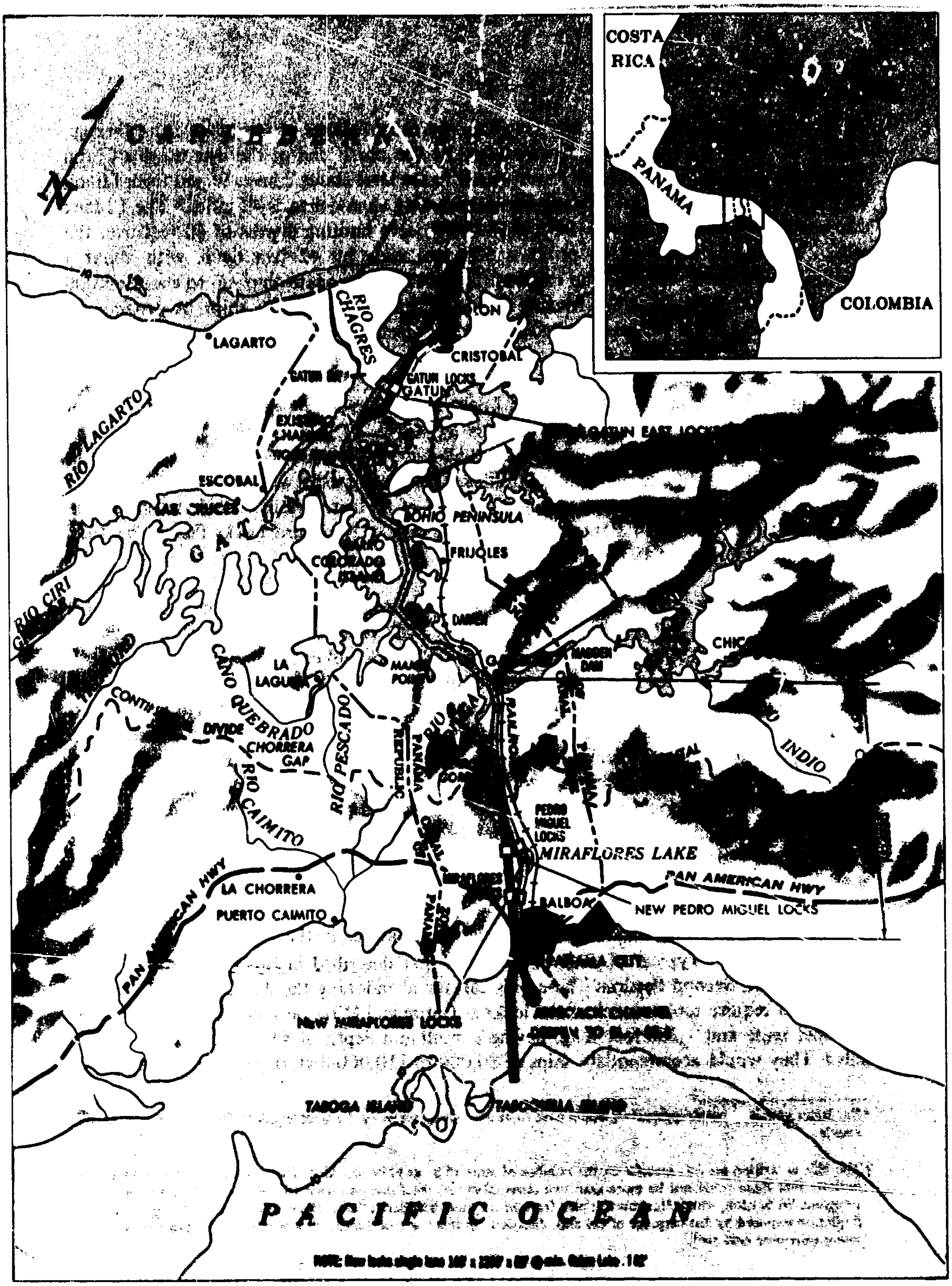
Third Locks Plan: The 1938 Third Locks Plan,[10] as subsequently modified, calls for construction of one additional lane of 140- by 1,200- by 50-foot locks adjacent to each existing set. The new locks would pass 105,000-dwt vessels and would increase the canal's annual transit capacity to about 35,000 ships. The existing locks would continue in use and Gatun Lake would remain at an average elevation of 85 feet. Details of this plan are shown in Figure 11-2. The 1964 Report estimated the cost of the Third Locks Plan to be $635 million ($800 million at 1970 price levels).

Terminal Lake Plan: The Terminal Lake Plan, considered first in the design of the existing canal, was proposed again in 1943. As described in 1947,[12] it calls for abandoning Pedro Miguel Locks, raising Miraflores Locks, and constructing one lane of large locks at both Miraflores and Gatun, capable of handling 110,000-dwt ships. Execution of this plan would increase the annual transit capacity to about 35,000 ships. The added locks would be 200- by 1,500- by 50-feet. Raising Miraflores Lake would provide an anchorage area above the Miraflores locks, reducing navigation hazards at the Pacific end of the Gaillard Cut. Operational efficiency would be increased by consolidating the Pacific locks. The existing two-lane locks at Gatun and Miraflores would continue in operation, and Gatun Lake would remain at its present level. Details of the plan are shown in Figure 11-3. The 1964 Report estimated the cost of this plan to be $946 million ($1.1 billion at 1970 price levels).

Terminal Lake Plan variations: A number of variations in the Terminal Lake Plan have been proposed.[40] Typical of such proposals is that described in H.R. 3792 and S. 2228, 91st Congress, Second Session. These bills call for abandoning the Pedro Miguel Locks and appear to require replacement of the locks at Gatun and Miraflores with two lanes of locks 140 feet wide and 1,200 feet long, having a minimum depth of 45 feet of water over the sills.† They would accommodate ships of 80,000 to 110,000 dwt, depending on the level of

*For larger vessels, present approaches would have to be extended, increasing the total length to 56 miles for 150,000 dwt vessels.

†The bills as written are not specific on the number of lanes of locks to be provided. They include cost limitations which indicate that there could not be more than two lanes; however, the figures on page 183 of House Document 474, 89th Congress, 2d Session, which illustrate the plan from which these bills derive, show three lanes of locks. In view of the cost limitation imposed by the language of the bills, discussion in this study of Terminal Lake Plan variations relates to 2 lanes unless otherwise indicated.



THIRD LOCKS PLAN

THE CANAL ZONE AND VICINITY

SCALE IN MILES

5 0 5 10

DEPTH IN FATHOMS

FIGURE 11-2

TERMINAL LAKE PLAN
THE CANAL ZONE AND VICINITY

FIGURE 11-3

SCALE IN MILES
5 0 5 10
DEPTH IN FATHOMS

Gatun Lake. The lake, now maintained between elevations 82 and 87 feet, would be regulated between 82 and 92 feet, requiring modification of the dam and spillway at Gatun. A terminal lake at Gatun Lake level would be formed above the new Miraflores Locks, improving conditions for navigation. Raising the level of the lakes would obviate the need for major excavation. Details of these proposals are shown in Figure 11-4. Transit capacity would be approximately equal to that of the existing canal after planned improvements. The bills proposing these variations include $850 million for construction; however, if 3 lanes of new locks were provided at each end to increase annual transits to about 35,000, construction costs would be about $1.4 billion.

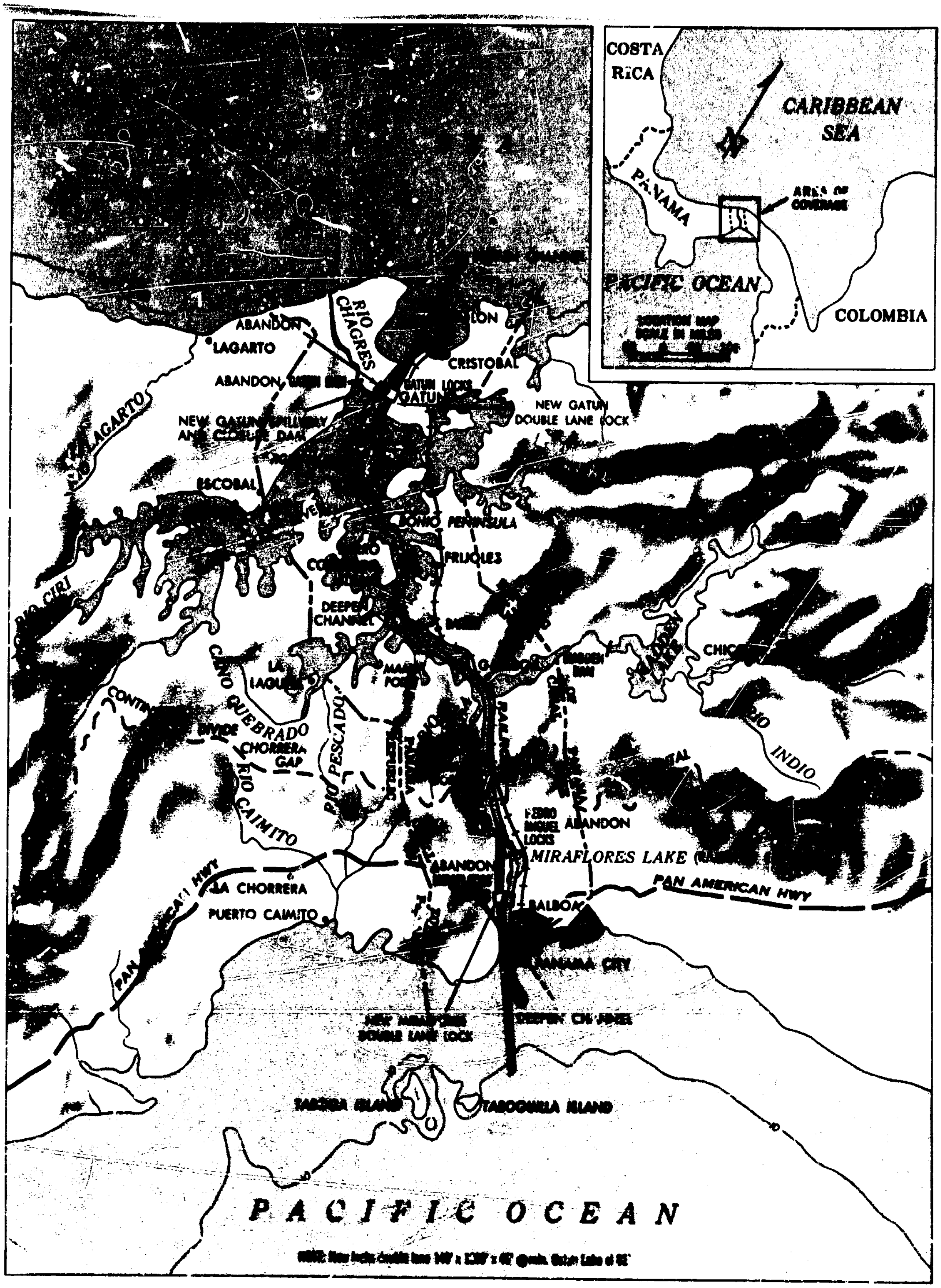
Deep Draft Lock Canal Plan: A plan[41] incorporating the most desirable features of previously proposed lock canal plans was developed during the current studies. To meet criteria applied in this study, the locks were designed to accommodate 150,000-dwt ships and flatter excavation slopes were assumed than those of earlier lock canal plans. The new plan calls for adding a lane of triple-lift locks to the existing 2 lanes at Gatun and constructing a separate lane of triple-lift locks at Miraflores to raise 150,000-dwt ships into a bypass around Pedro Miguel at the level of Gatun Lake. Details of the plan are shown in Figure 11-5. It has the advantage of permitting continued operation of all existing locks throughout their useful lives. It would accommodate 35,000 transits per year. Its initial cost would be about $1.5 billion. Additional costs would be incurred when the existing locks could no longer be used economically and would have to be replaced. Replacement would be accomplished with some interference to traffic but would consolidate all three lifts on the Pacific side at Miraflores, raising Miraflores Lake to the level of Gatun Lake.

Construction: Construction systems for plans other than that for the Deep Draft Lock Canal Plan were not analyzed in detail; however, except for the Terminal Lake Plan variations, they probably would be similar to the system contemplated for the Deep Draft Lock Canal. In the Terminal Lake Plan variations, almost all channel excavation would be avoided by raising the level of Gatun Lake.

Construction effort involved in the Deep Draft Lock Canal Plan would be about evenly divided between lock construction and channel excavation. The new locks would take advantage of the Third Locks excavations made in 1940-1942. Channel excavation would be acco[illegible]shed mainly by dipper dredges and spoil would be removed in scows. [illegible]nstruction would take about 10 years.

Problem areas: The 160- by 1450- by 65-foot locks and their gates would be especially large and massive, but their design and construction are within the capabilities of existing technology. To achieve expected capacity, a high speed filling and emptying system would be required for these locks.

All lock canals have the inherent handicap of needing extremely large quantities of lockage water. On Route 15 this requirement can be met by pumping ocean water into Gatun Lake, or possibly by recirculating fresh water. The first method would render Gatun Lake brackish, thus changing some ecological characteristics of the area, while the second would involve unusual engineering problems. Both methods would entail costly pumping operations.



S. 2228 AND H.R. 3792 (91 st CONGRESS) PLAN

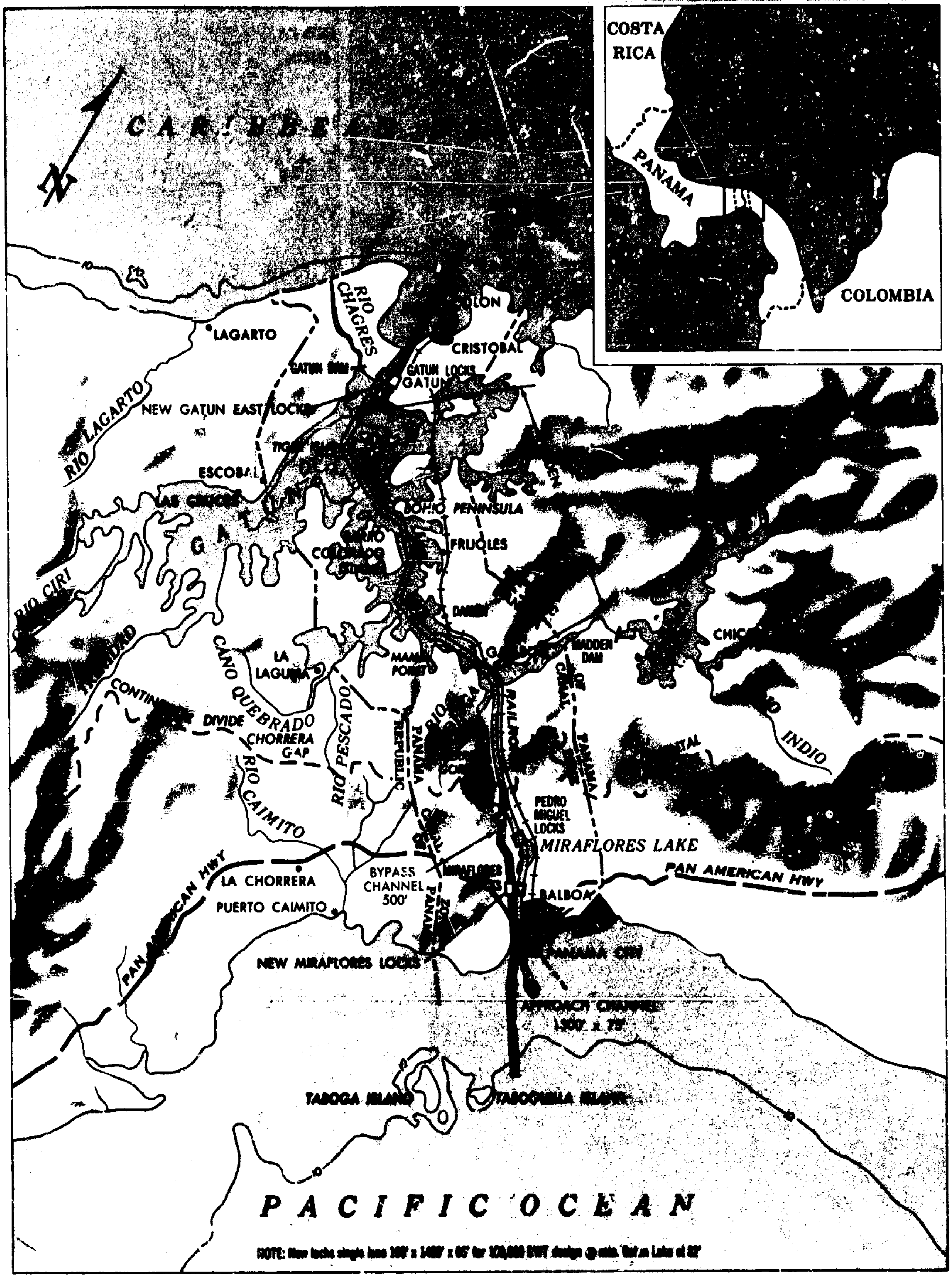
THE CANAL ZONE AND VICINITY

FIGURE 11-4

SCALE IN MILES

5 0 5 10

DEPTH IN FATHOMS



DEEP DRAFT LOCK CANAL
THE CANAL ZONE AND VICINITY

SCALE IN MILES
5 0 5 10
DEPTH IN FATHOMS

FIGURE 11-5

Construction of any of these options would interfere with traffic through the Gaillard Cut, Miraflores Lake, and Pedro Miguel and Miraflores Locks. The Terminal Lake Plan, in particular, would reduce transiting capacity significantly during construction.

Areas of weak rock where extensive slides occurred during construction of the Panama Canal would have to be excavated in deepening and widening the channel. Extreme care would be required during excavation to avoid massive slides which might block the canal.

Any further increase in the capacity of a lock canal after construction would be difficult. Larger locks would have to be provided either in addition to, or as replacements for, at least 1 complete lane of locks at each end of the canal; additional widening of the Gaillard Cut would be necessary. It may be possible, however, to capitalize on the demonstrated ability of small ships to pass in the Gaillard Cut. This may allow capacity to increase up to 40,000 transits per year, the estimated capacity of 3 lanes of locks, without additional channel widening.

Except for the Terminal Lake Plan variation, all plans make at least some use of the present lock structures. These locks were built at a time when concrete technology was in its infancy. They are nearly 60 years old and, while the concrete has been tested and appears to be in good condition, the remaining useful life of the locks cannot be predicted accurately. The estimated cost of replacement is $800,000,000.*

The Terminal Lake Plan variation would raise the level of Gatun Lake. This would make replacement of the existing locks necessary and would require raising Gatun Dam and making major modifications in the spillway. Fluctuation of the lake level over a 10-foot range would cause greater environmental changes than any of the other lock canal plans.

Except for the Deep Draft Lock Canal Plan, none of these plans meets present forecasts of traffic demands after the year 2000, with respect to both ship size and annual transits. As now conceived, the Deep Draft Lock Canal Plan could not accommodate the larger attack aircraft carriers of the U.S. Navy; the locks would be too narrow to hold angle decked ships. This limitation could be overcome by providing a lane of locks with very low lifts, but such an arrangement would add significantly to the transit time of all ships using that lane, and would increase construction and operating costs. A preferable solution might be to provide wider locks; however, this also would increase costs, especially those for lockage water supply. Construction costs of a lock canal which would accommodate large carriers are estimated to be approximately $2.3 billion. Annual operating costs for such a canal would be about $78 million at 35,000 transits per year.

Summary data: The characteristics of the Deep Draft Lock Canal Plan are given in Table 11-1.

*The date of replacement cannot be predicted, but the year 2000 is being used in Annex III, *Study of Canal Finance*, as the earliest probable date.

TABLE 11-1

CHARACTERISTICS OF ROUTE 15

Deep Draft Lock Canal Plan	
Canal dimensions	500 ft x 65 ft (centerline depth 75 ft.)
Lock dimensions	160 ft x 1450 ft x 65 ft
Length of land cut	36 miles
Length of approaches	20 miles
Design vessel	150,000 dwt
Capacity	35,000 transits/yr. (25 hrs average TICW)
Construction time	10 years
Excavation volume	560,000,000 cu. yd.
Cost of new locks[a]	$550,000,000
Excavation cost	$570,000,000
Other facilities	$120,000,000
Contingencies	$190,000,000
EDS&A[b]	$100,000,000
TOTAL CONSTRUCTION COST	$1,530,000,000
Operation and maintenance:[c]	
Fixed costs	$51,000,000/year
Variable costs	$580/transit

[a]Cost for a Route 15 option with locks which would accommodate a modern attack aircraft carrier is estimated at $2.3 billion.

[b]Engineering, design, supervision, and administration

[c]If the deep draft locks were operated as an adjunct to the Panama Canal Company, the Company's fixed operation and maintenance costs would be increased $13 million a year and variable operation and maintenance would amount to $1,600 per transit for transits over 26,800 a year. Of the $1,600, $800 is for pumping locakge water.

TABLE 11-1

CHARACTERISTICS OF ROUTE 15 (Cont'd)

	Favorable	Unfavorable
Supporting facilities	Excellent facilities exist in the Canal Zone and in the metropolitan area of the Republic of Panama.	
Existing harbor facilities	Excellent facilities exist in the Canal Zone in Limon Bay and at Balboa.	Existing facilities are not deep enough to accommodate vessels of 150,000 dwt.
Harbor potential	Low-lying areas close to the ends of the alinement could be dredged to provide more anchorage.	All protected areas available for expansion require dredging.
Approaches/ coasts		Approaches are relatively long.
Tidal currents	Only very low currents exist in the sea-level sections.	No choice available to transit ships with following or against breasting currents.
Routes of communication	The Canal Zone and metropolitan Panama provide excellent communications facilities; including a railroad, transisthmian and coastwise roads, airfields and water access through the existing canal.	
Terrain	Construction could utilize the present canal alinement and the Third Locks excavations.	
Geology	The geology is well documented.	Known areas of weak rock would require flat slopes and extreme care to avoid risks of slides blocking the canal during excavation.
Flood control and river diversion	No additional stream diversion would be necessary.	
Local development	The affected area already supports interoceanic canal commerce, and should accommodate construction without any unusual stresses.	

TABLE 11-1

CHARACTERISTICS OF ROUTE 15 (Cont'd)

	Favorable	Unfavorable
Construction features	Access is very easy. The common labor supply is plentiful. A good data base exists to support design.	There are risks of slides which might block canal traffic. Tight traffic control would be required to minimize interference between dumping scows and canal traffic. Locks and gates would be massive structures requiring special attention.
Environmental impact	Presence of locks presents a substantial barrier to interoceanic biota transfer. Overall environmental impact would be the least of all canal alinements considered.	If ocean water pumping is required, Gatun Lake would become brackish and interoceanic transfer of biota would increase. Spoil disposal in Gatun Lake may affect the ecology adversely.
Expansion possibilities		Another lane of locks and widening of the Gaillard Cut for two-lane traffic would be required. Further expansion on this alinement would be very costly.
Miscellaneous	Construction would be in territory now under U.S. administration.	Lockage water for transits much over 15,000/year would have to be provided by pumping sea water or recirculating lake water. Operation and maintenance costs for a lock canal are inherently higher than those of a sea-level canal. Plans would not accommodate large attack aircraft carriers. Capacity of the present canal would be reduced during several months of the construction period.

CHAPTER 12

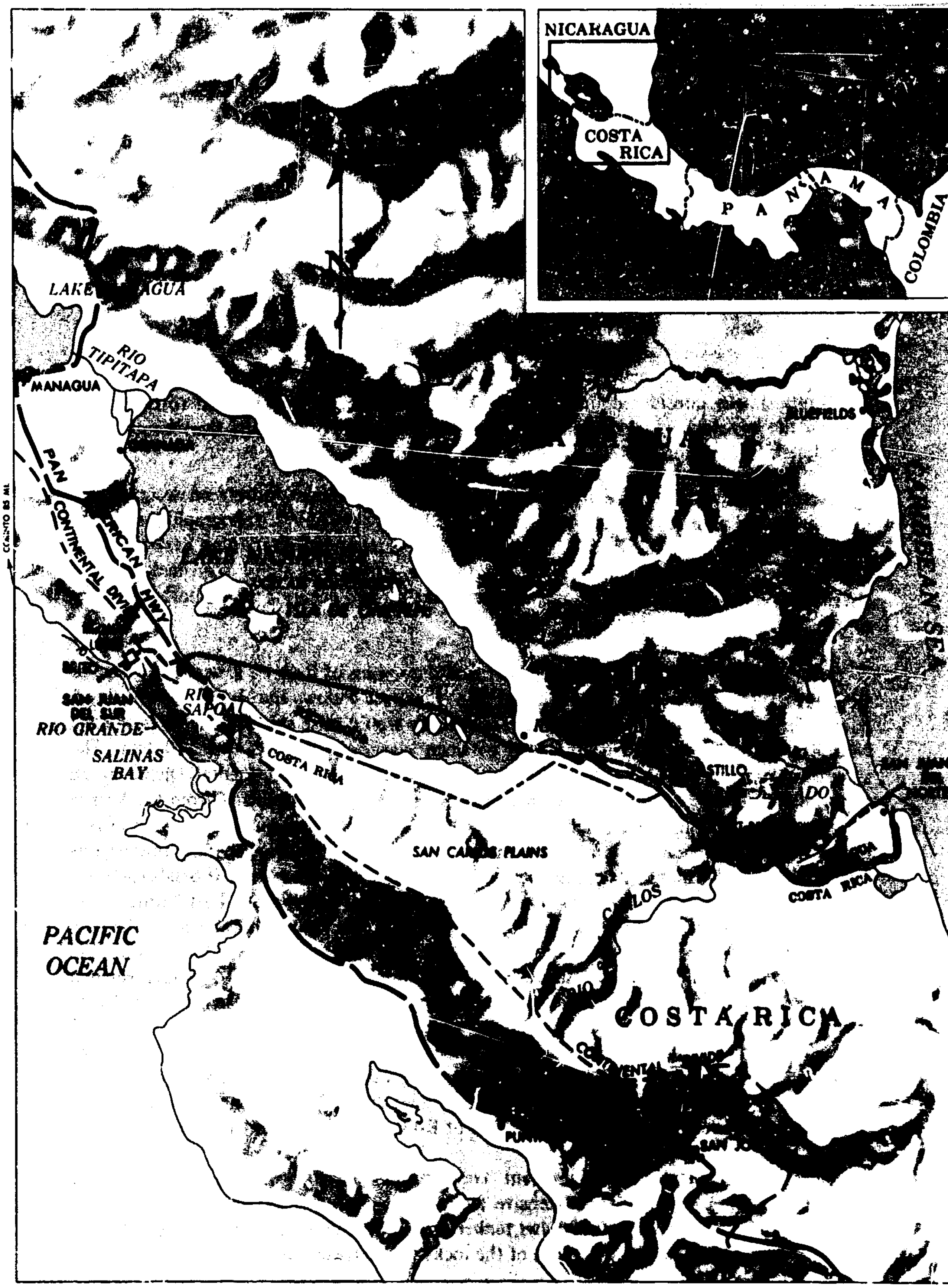
ROUTE 5 - NICARAGUA LOCK CANAL

Route 5 was considered only as a lock canal option. It was studied to determine whether the best lock canal alternatives might lie along some other route than Route 15. A more detailed discussion of Route 5 is presented in Appendix 11.

Accuracy of estimates: Analysis of Route 5 was based almost entirely on designs made in connection with the canal studies of 1931 and 1947,[8,12] topographic mapping performed in 1966 by the Inter American Geodetic Survey and Army Map Service, and a brief field reconnaissance made in 1969. Only a conceptual study was made of this alternative and estimates of its costs are considerably less accurate than those for other routes.

Route 5 trace: (See Figure 12-1.) The Pacific terminus of Route 5 is near the village of Brito, 10 miles northwest of San Juan del Sur. The trace follows the Rio Grande Valley 5 miles inland to Miramar, where twin triple-lift locks would raise ships to the level of Lake Nicaragua which would be maintained between elevations of 105 and 110 feet. The alinement continues up the Rio Grande Valley, crosses the Continental Divide at an elevation of about 200 feet, and enters Lake Nicaragua 15 miles inland from the Pacific Ocean. After a 70-mile-long reach across the lake, the land cut would begin again at San Carlos where Lake Nicaragua drains into the San Juan River. The trace generally follows this river for about 55 miles to its confluence with the San Carlos River where it bends eastward to pass through a series of low hills. These hills culminate in the so-called East Divide which the trace traverses at a peak elevation of nearly 400 feet. On the Caribbean side of the East Divide a second set of locks would provide the transition to sea level. From this location the trace follows the valley of the Deseado River, continuing northeast for 14 miles through a deltaic swamp to enter the Caribbean Sea about 4 miles north of San Juan del Norte (Greytown). The Pacific approach is about 1 mile in length, that on the Atlantic about 3 miles. The total length of the route is 177 miles, including approaches. Except for Lake Nicaragua and a narrow, highly-developed strip lying west of it, the region through which the trace passes is covered by tropical forest in which the few inhabitants practice slash-and-burn agriculture. A centerline profile of Route 5 is shown in Figure 12-2.

Construction: The most significant construction features of Route 5 would be triple-lift, double-lane locks and extensive facilities to impound the San Juan River. The locks, capable of carrying a 150,000-dwt tanker, would have dimensions of 160 by 1,450 by 65 feet. Although the height and width of the locks would require the use of large lock gates



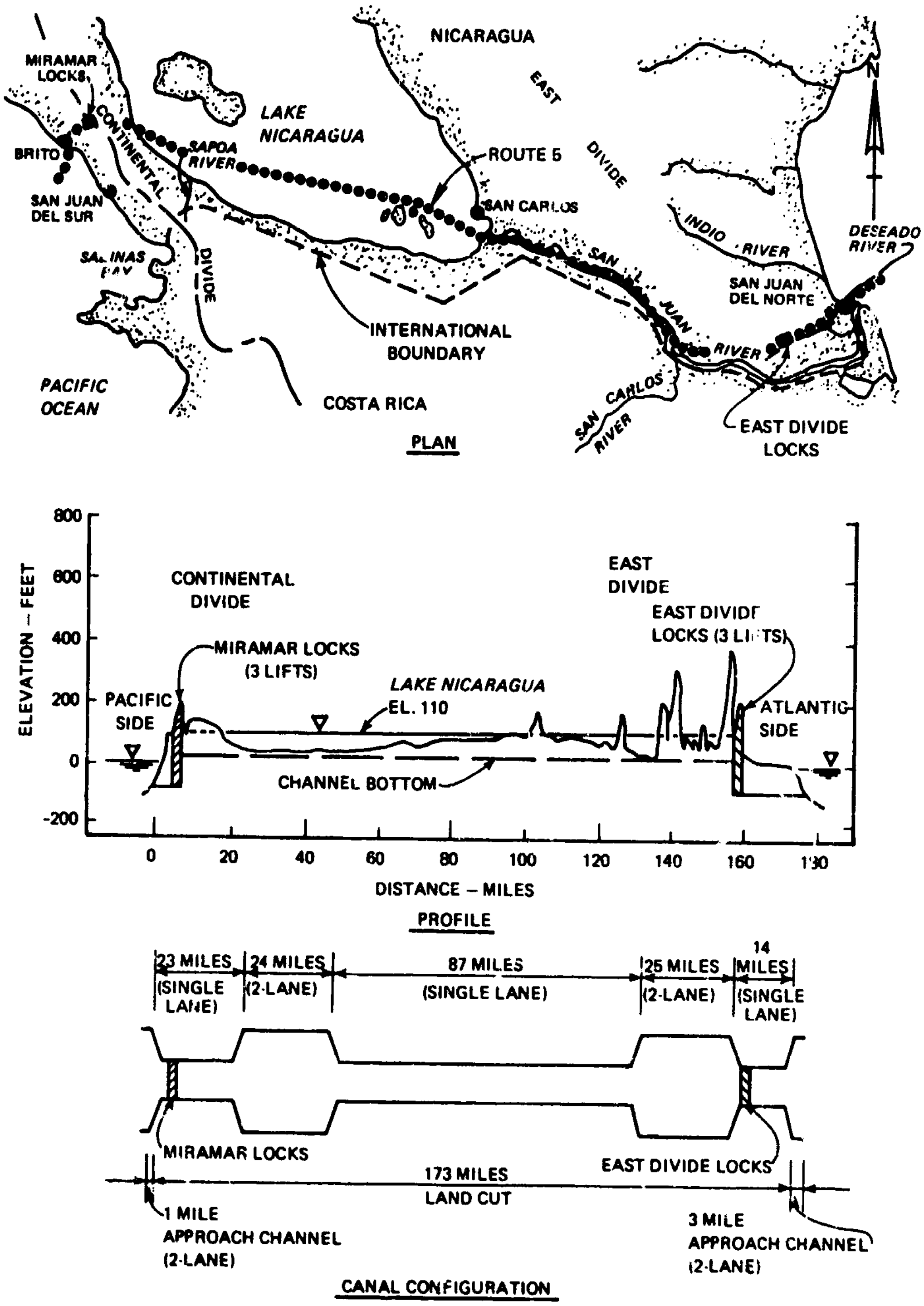
ROUTE 5
NICARAGUA-COSTA RICA BORDER AREA

SCALE IN MILES

10 0 10 20 30

DEPTHS IN FATHOMS

FIGURE 12-1



ROUTE 5

FIGURE 12-2

and machinery, their design and construction are within the capabilities of current technology. A high-speed filling and emptying system would be needed to speed vessels through the locks. Impoundment of the San Juan River would reduce excavation requirements and possibly provide passing sections.

Since most streams in the area flow into Lake Nicaragua, requirements for river diversion would be relatively small. It would not be difficult to regulate lake levels and the extensive drainage area tributary to the lake would supply ample lockage water.

Because of the lack of development in this region, most facilities required for constructing and operating the canal would have to be provided. These would include an all-weather transisthmian highway; harbors; airfields; administrative, maintenance, and residential buildings; lateral roads, and highway bridges. The limited protection offered by both coastlines and the poor foundation conditions on the Atlantic might dictate that harbor facilities be located inland.

A lock canal on Route 5 would take about 12 years to build and would cost approximately $6 billion. The nearly 2 billion cubic yards of excavation involved in the project account for a large part of this cost.

Problem areas: The length of the canal prevents transits within the 20-hour average TICW criteria. At rated capacity–25,000 annual transits–it is estimated that the average TICW would be 36 hours. To achieve even these sub-standard conditions, two passing sections must be installed–one immediately inland from the East Divide locks and the other at the west end of Lake Nicaragua.

Provisions must also be made for potential seismic effects associated with the volcanic nature of the region.

The dimensions of Route 5 would not accommodate a 250,000-dwt ship under any conditions. The locks would not pass a modern attack aircraft carrier. To provide one lane with locks big enough to carry these large ships would cost an additional $600 million.

Summary data: The characteristics of Route 5 are summarized in Table 12-1.

TABLE 12-1

CHARACTERISTICS OF ROUTE 5

Canal dimensions	500 ft x 65 ft[a] (centerline depth 75 ft)
Lock dimensions	160 ft x 1,450 ft x 65 ft
Length of land cut	173 miles
Length of approaches	4 miles
Design vessel	150,000 dwt
Capacity[b]	25,000 transits/yr (36 hrs. average TICW)
Construction time	12 years
Excavation volume	1,700,000,000 cu. yd.
Cost of locks	$1,200,000,000[c]
Excavation cost	$2,200,000,000
Other facilities	$1,300,000,000
Contingencies	$ 600,000,000
EDS&A[d]	$ 400,000,000
TOTAL CONSTRUCTION COST	$5,700,000,000
Operation and maintenance:	
Fixed cost	$71,000,000/year
Variable cost	$1,240/transit

[a]Includes 49 miles of two-lane channel necessary to obtain capacity.

[b]Length of canal prohibits operation within 20 hour TICW standard.

[c]Includes the Conchuda Dam on the San Juan River.

[d]Engineering, design, supervision, and administration.

	Favorable	Unfavorable
Supporting facilities	The small city of Granada at the north end of Lake Nicaragua could provide limited support.	No facilities exist with substantial capability of supporting construction and operation of an interoceanic canal.
Harbors	Limited small boat facilities exist at San Juan del Sur.	No deep draft facilities exist in the vicinity of the route.
Harbor potential	Good potential exists at Salinas Bay, 35 miles southeast of Brito.	Potential sites on Atlantic are hampered by regular coastline and marshy terrain.

TABLE 12-1

CHARACTERISTICS OF ROUTE 5 (Cont'd)

	Favorable	Unfavorable
Approaches/ coasts	Deep water is close in on both coasts. Salinas Bay offers protection on the Pacific.	No protected areas exist along this stretch of the Atlantic coast.
Tidal currents	Locks would prevent currents from interfering with navigation.	No choice available to transit ships with following or against breasting currents.
Routes of communication	Waterborne traffic exists on Lake Nicaragua and the San Juan River. The Pan American Highway crosses the alinement between Brito and Lake Nicaragua.	No transisthmian road or railroad and no roads exist on the Atlantic side; no interior roads lead east from Lake Nicaragua. Managua has the nearest all-weather airfields.
Terrain	Spoil disposal areas are readily available. Maximum cut would be only 400 feet above sea level. Topography of the San Juan River Valley is suitable for an extension of the level of Lake Nicaragua over 50 miles downstream by construction of a dam.	There are two mountain ranges to traverse. Much of the land cut on the Atlantic side is heavily forested. The Atlantic coastal region is a swampy alluvial plain. Only the divide region is relatively cleared.
Geology		Very little is known of subsurface conditions. This is an area of volcanic activity.
Flood control and river diversion	Flood diversion problems would be minimized by use of Lake Nicaragua as a summit pool. Lake provides adequate water for operations.	A large impounding dam would be required to bring the San Juan River up to summit pool elevation.
Construction features	Access would be relatively easy by Lake Nicaragua and the San Juan Valley.	The locks and lock gates would be massive structures requiring special attention. The level of Lake Nicaragua must be maintained.

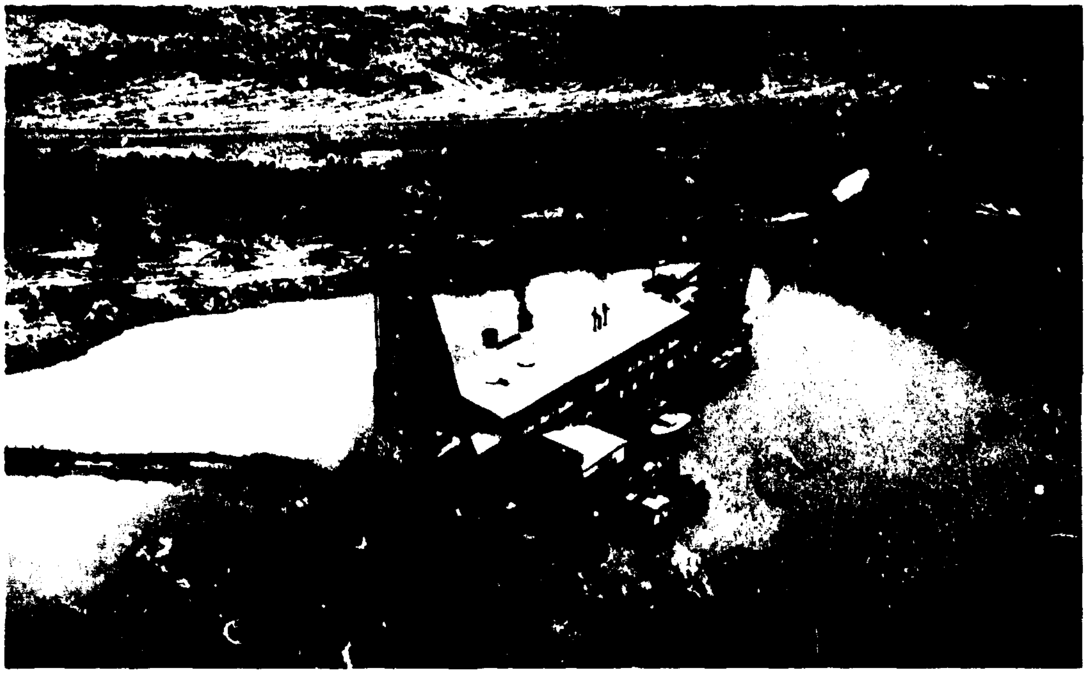
TABLE 12-1

CHARACTERISTICS OF ROUTE 5 (Cont'd)

	Favorable	Unfavorable
Environmental impact	A large choice of spoil disposal areas exists. A small number of inhabitants would be displaced. Detrimental environmental impact would be minimized.	
Expansion possibilities	No technical or construction problems are foreseen that would be different from those encountered in the original construction.	The need for additional locks and bypasses would make expansion very expensive.
Local development	The area east of Lake Nicaragua is almost completely undeveloped. There are scattered patches of subsistence agriculture in the jungle. Population density is about five people per square mile.	
Miscellaneous	Of the routes studied this is the shortest lock canal route from New York to San Francisco.	To take advantage of the existing San Juan River Valley, the route would be relatively angular.

One of the larger ships that use the Panama Canal. Note the small clearance between the ship and the lock wall.

Large ships such as this require tugs to assist them in passing through the Panama Canal.



The Gaillard being widened using a large pipeline dredge.

The Panama Canal Company is undertaking a program to increase the capacity of the canal. A major item, widening the Gaillard Cut from 300 to 500 feet, was completed in 1970.

CHAPTER 13

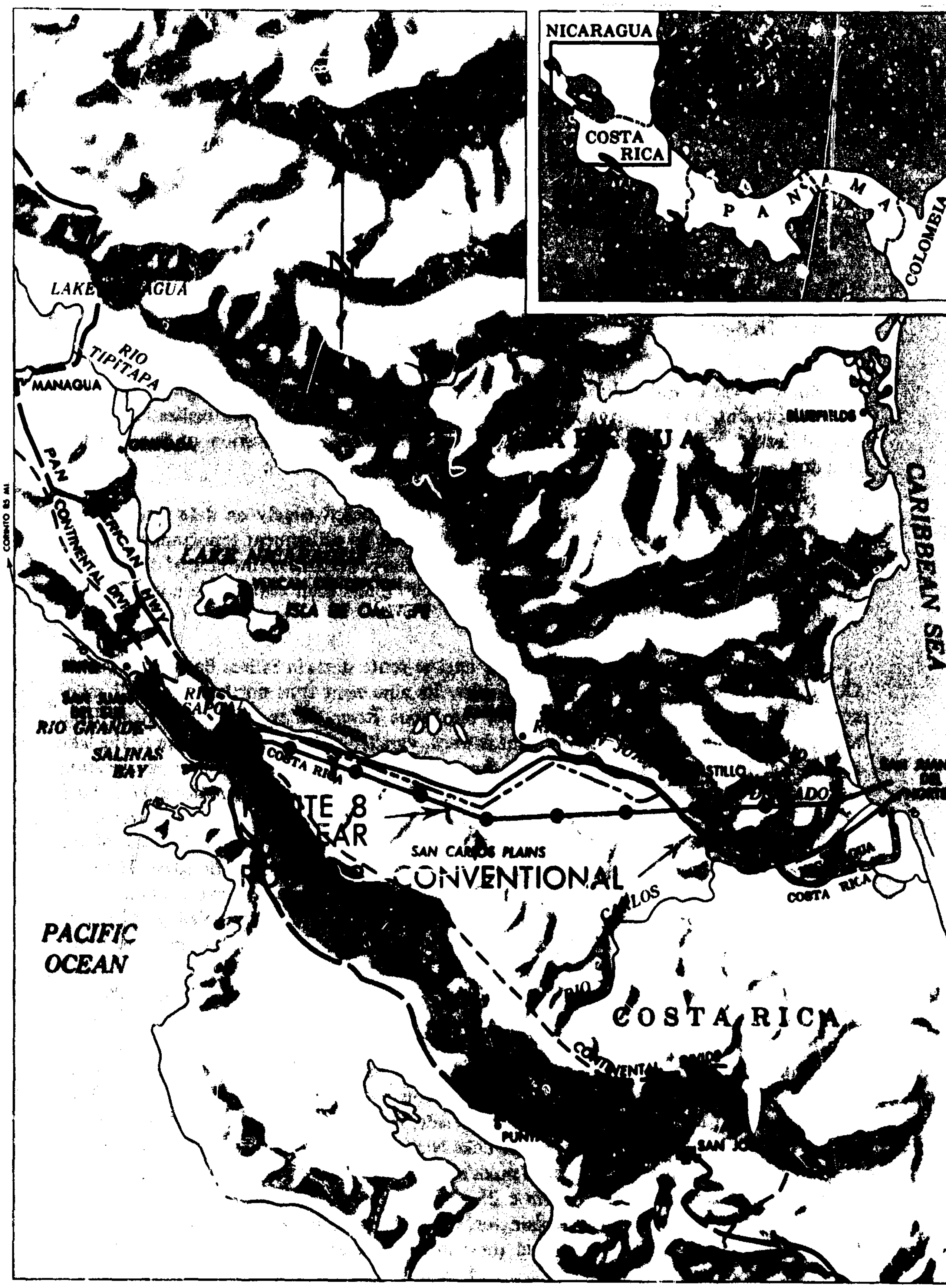
ROUTE 8—NICARAGUA-COSTA RICA BORDER REGION SEA-LEVEL CANAL

Route 8 was considered for both all-conventionally excavated and all-nuclear excavated sea-level options. Two different alinements were studied, permitting full realization of the capabilities of each method of excavation. A more detailed discussion of this route is included in Appendix 11.

Accuracy of estimates: Analysis of Route 8 was based largely on data assembled in connection with previous studies,[10,12] supplemented by subsequent topographic surveys. Geologic conditions along this route are poorly defined. Because of the lack of data on the route, the analysis of alternatives for its construction, and their costs, were not refined to the degree achieved for other routes.

Route 8 trace: (See Figure 13-1.) The nuclear route starts in Salinas Bay on the Pacific Ocean near the Nicaragua-Costa Rica border. Its alinement runs northeastward 12 miles across the Continental Divide and down the Sapoa River Valley. Five miles from Lake Nicaragua it bends eastward, then southeastward, paralleling the southern shore of the lake approximately 5 miles inland. It passes through the marshy lower edge (average elevation 110 feet) of the San Carlos Plains on the Costa Rican side of the international boundary. Beyond the southern tip of the lake the route turns east, crossing the San Juan River south of the village of El Castillo. Continuing eastward, it passes through a 30-mile reach of the eastern cordillera before dropping into the Indio River delta on the Atlantic coast. The total length of this alinement is 140 miles; the peak elevation at its western end is about 1,000 feet, while that on the East Divide is nearly 900 feet. Except in the Sapoa Valley, the region through which the trace passes is undeveloped and heavily forested; its few inhabitants practice subsistence agriculture.

The conventionally excavated canal alinement also starts in Salinas Bay but follows a small valley up to the Continental Divide which is only 3 miles from the coast. After crossing the divide, it turns abruptly northward to follow the Sapoa River toward Lake Nicaragua. Two miles from the lake, the trace turns eastward about 120 degrees to parallel the shoreline at an average distance of 2 miles. This portion of the route generally follows the international boundary on the Nicaraguan side, intersecting the San Juan River 10 miles downstream from the southeastern tip of Lake Nicaragua. From that point the trace follows the San Juan River to a point about 5 miles above its confluence with the San Carlos River. There it turns generally eastward in a 25-mile cut through the eastern cordillera. After passing through a marshy coastal plain for 10 miles, the alinement enters the Caribbean between the mouths of the Indio and the San Juan Rivers. Its total length is 176 miles,



ROUTE 8
NICARAGUA-COSTA RICA BORDER AREA

SCALE IN MILES
10 0 10 20 30

DEPTHS IN FATHOMS

FIGURE 13-1

including approaches. The peak elevation on the Continental Divide is approximately 750 feet; on the East Divide it is about 400 feet.

Profiles of both alinements, based on maps prepared by the Inter American Geodetic Survey and the Army Map Service, are shown in Figures 13-2 and 13-3.

Construction: The nuclear alinement would take approximately 12 years to build and would cost more than $5 billion. Its excavation would require about 740 separate nuclear explosive charges with yields ranging from 200 kilotons to 3 megatons. These would be detonated in groups; nearly 80 separate detonations would be required. The largest total yield for a single detonation, the Continental Divide cut, would be 12.5 megatons.

Construction of the conventionally excavated sea-level canal, with a by-pass to provide the required transit capacity, would take about 18 years and would cost approximately $11 billion. The principal element in this cost would be excavation, estimated to be about 7 billion cubic yards. Most of this would be accomplished by open-pit mining techniques using rail haul of spoil to lateral disposal areas.

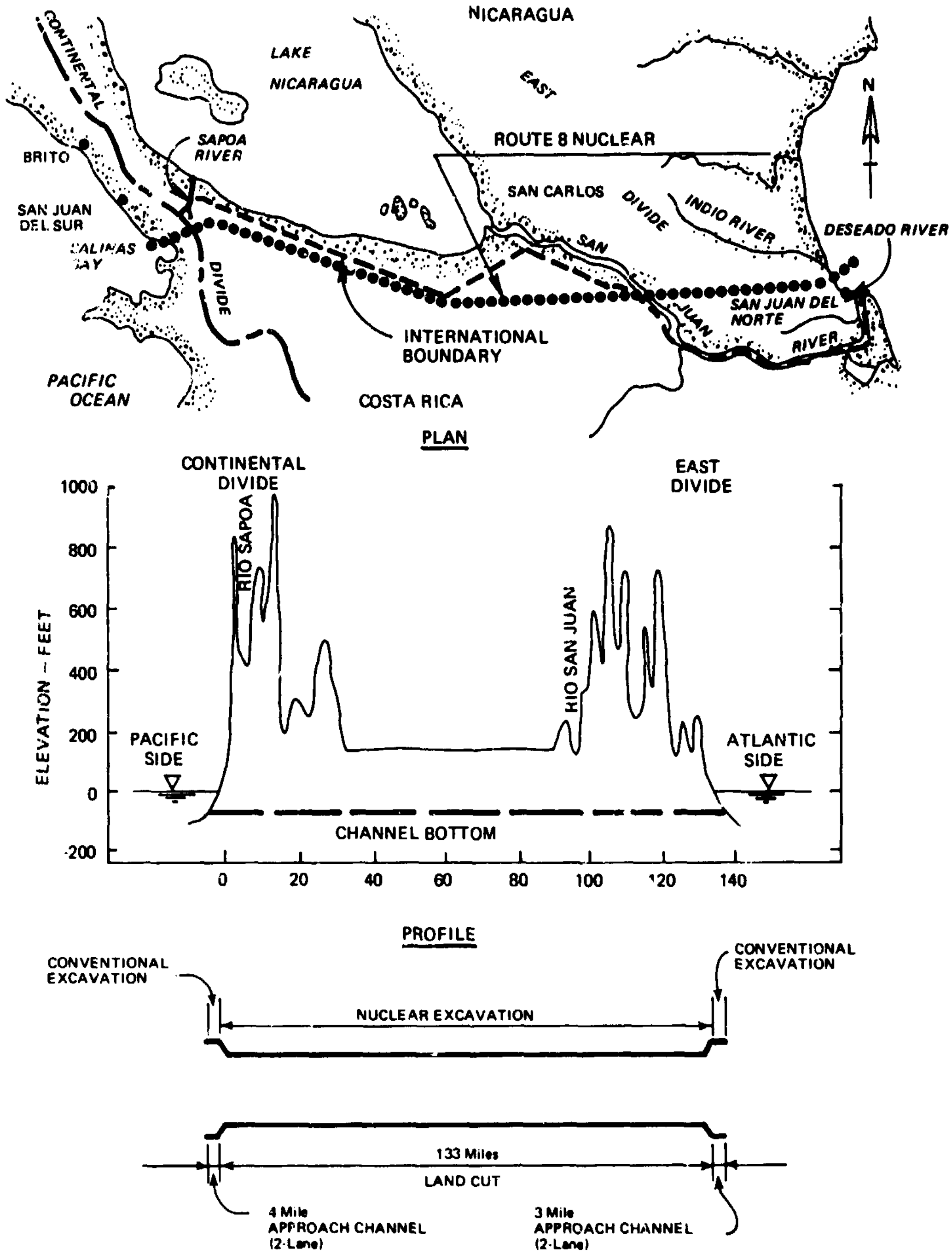
Both Route 8 options require regulation of the San Juan River. This would involve a substantial engineering effort, including damming the river below San Carlos to regulate Lake Nicaragua and providing appropriate inlet works with energy dissipation structures at the junction of the canal and the river. Streams flowing northward across the San Carlos Plains into Lake Nicaragua would be intercepted and their flows brought into the canal through inlet structures.

Because of the lack of development in this area, all facilities required for building and operating a canal would have to be provided. These would include an all-weather transisthmian highway, port facilities, airfields, administrative and residential facilities, lateral roads, and highway bridges.

Problem areas: Nuclear excavation would involve an extremely costly safety program. The minimum exclusion area would cover more than 20,000 square miles, including about a third of Costa Rica (see Figure 13-4). Nearly 675,000 people would have to be evacuated during nuclear detonation periods. The large area specified for evacuation was dictated by highly conservative airblast considerations. The area would be significantly smaller and much less costly to evacuate if radioactivity and seismic effects were the controlling factors, but the total number of people involved would still be much larger here than on any other nuclear route considered in this study.

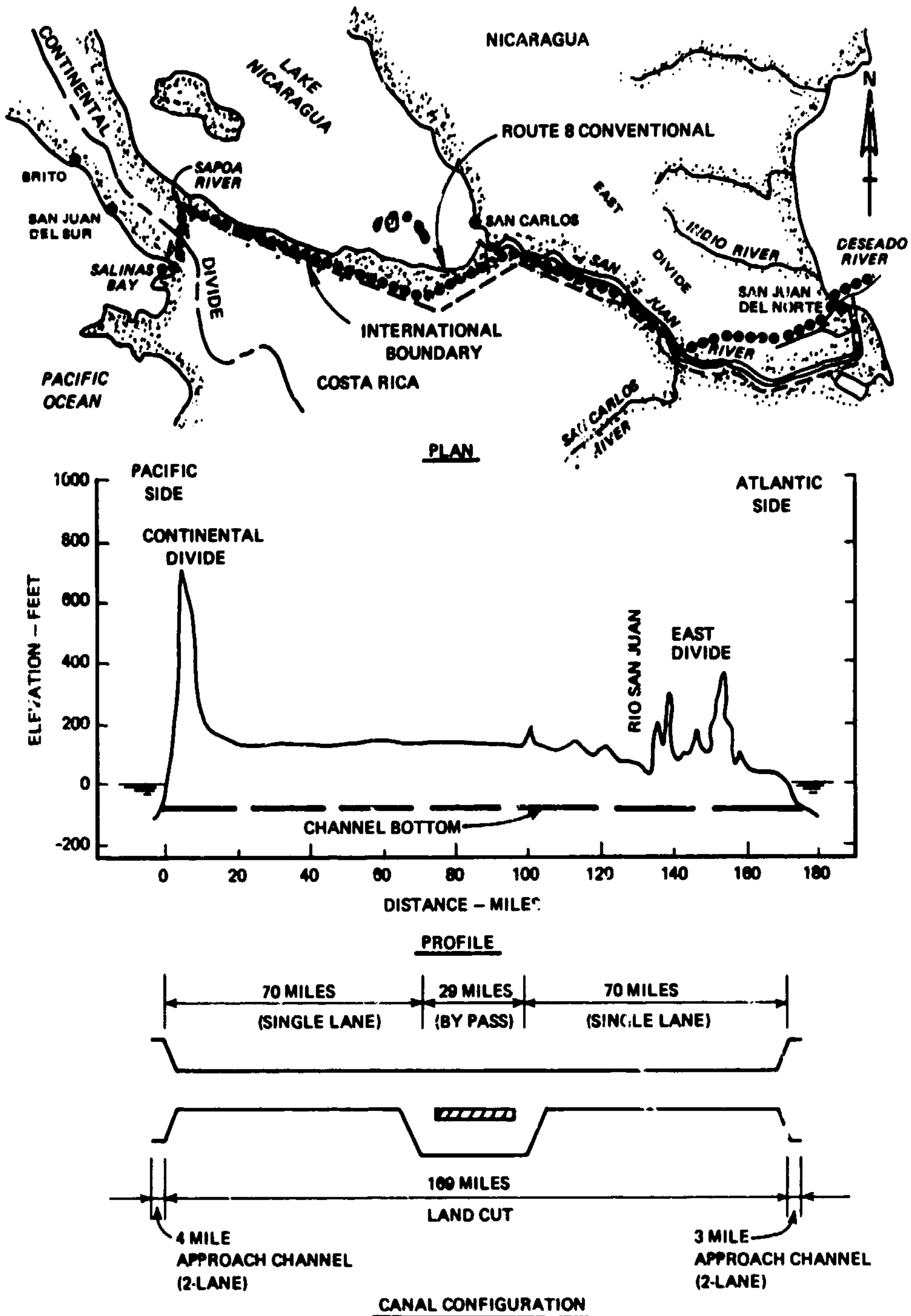
Route 8 Conventional is longer than any other route selected for this study, and it has the greatest angularity, two features which would adversely affect operation of the completed canal. Its length also would tend to increase the need for passing sections to obtain additional transiting capacity.

The extensive river systems crossing these alinements and the need to maintain the elevation of Lake Nicaragua present major problems. The drainage area of the lake covers 10,000 square miles, from which nearly all runoff flows down the San Juan River to the Caribbean Sea. In periods of peak flow the San Juan River discharges 70,000 cfs, most of which would have to be diverted from the canal. A 60-mile dike constructed from excavated spoil might be required south of Lake Nicaragua to ensure separation of the lake waters from the canal and to sustain the desired lake elevation.



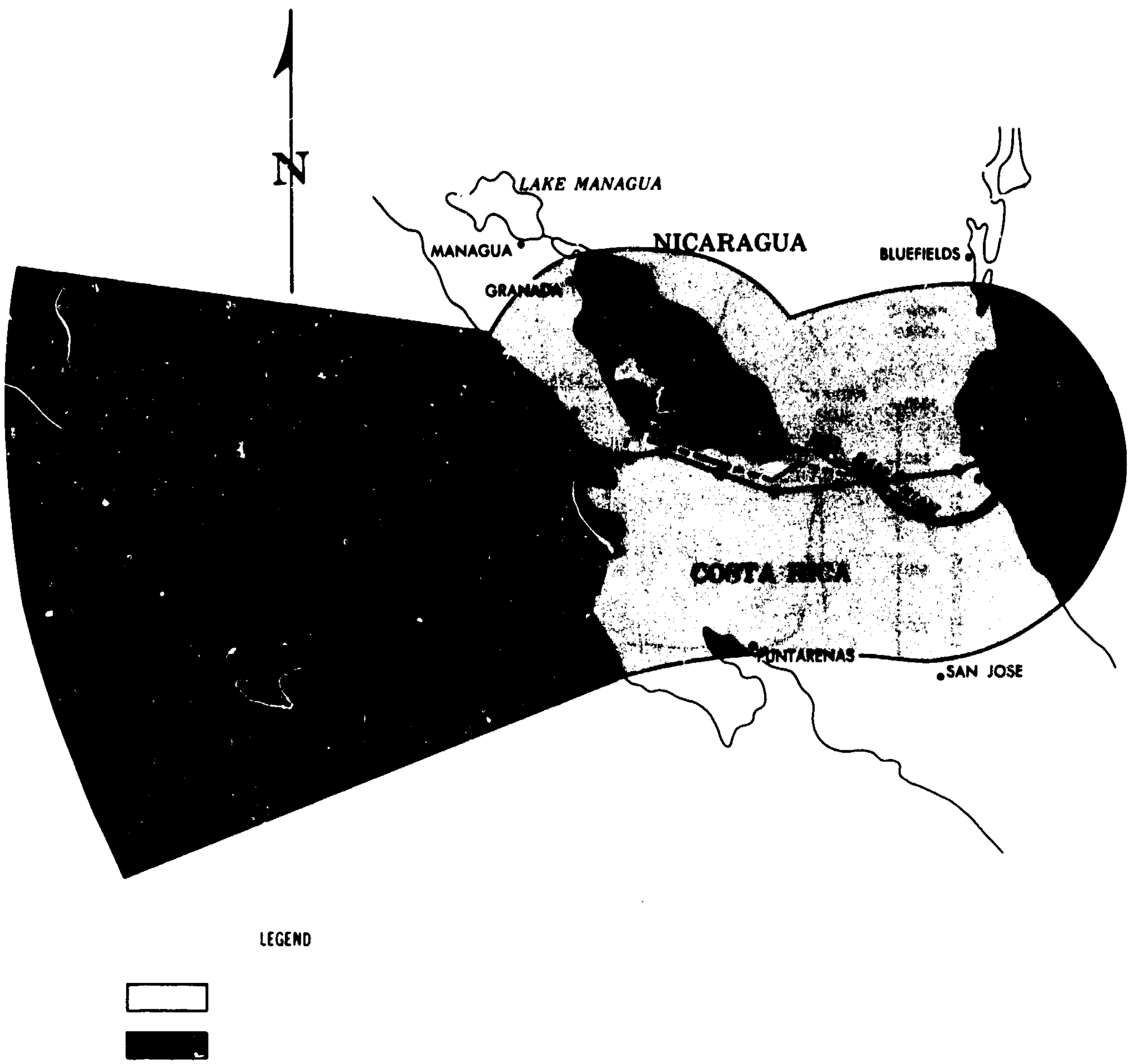
CANAL CONFIGURATION
ROUTE 8 NUCLEAR

FIGURE 13-2



ROUTE 8 CONVENTIONAL

FIGURE 13-3



LEGEND

ROUTE 8 NUCLEAR EXCLUSION AREA

SCALE IN MILES
20 0 20 40

FIGURE 13-4

Knowledge of the geology at the canal cut depths is limited. The presence of volcanic activity and the flat terrain south of Lake Nicaragua suggest that there may be weak materials such as have been found on other routes where extensive subsurface investigations have been made. If present, these materials would increase construction costs.

The terrain, which is almost completely covered by dense jungle and extensive marshy areas, would hinder construction. Access to the route by means other than water is extremely limited except at its western end. The canal would cut off the San Carlos Plains from the lake. Access to construction sites might be complicated by political problems growing out of the proximity of the trace to the international boundary in this reach.

Summary data: The characteristics of the nuclear alinement are summarized in Table 13-1; those of the conventionally constructed alinement are in Table 13-2.

TABLE 13-1

CHARACTERISTICS OF ROUTE 8 NUCLEAR[a]

Canal dimensions	1,000 x 75 feet (minimum)
Length of land cut	133 miles
Length of approaches	7 miles
Design vessel	250,000 dwt
Capacity	200,000 transits/yr (20 hrs average TICW)
Construction time	12 years
Excavation cost	$ 850,000,000
Other facilities[b]	$3,350,000,000
Contingencies	$ 630,000,000
EDS&A[c]	$ 340,000,000
TOTAL CONSTRUCTION COST	$5,170,000,000
Operation and maintenance:	
Fixed costs	$50,000,000/year
Variable costs	$1,100/transit

[a]Based on nuclear excavation throughout the length of the route, except for the ocean approaches which would be 1400 by 85 feet.

[b]Includes evacuation costs.

[c]Engineering, design, supervision and administration.

	Favorable	Unfavorable
Supporting facilities	The small city of Granada on the north end of Lake Nicaragua could provide limited support.	None exist capable of providing substantial support to construction and operation of the interoceanic canal.
Harbors	Limited small boat facilities exist at San Juan del Sur.	No deep draft facilities exist in the vicinity of the route.
Harbor potential	Good potential exists in Salinas Bay.	Potential sites on the Atlantic are limited by regular coastline and marshy terrain.
Approaches/ coasts	Deep water lies close in on both coasts. Salinas Bay offers protection on the Pacific.	No protected areas exist along this stretch of the Atlantic coast.

TABLE 13-1

CHARACTERISTICS OF ROUTE 8 NUCLEAR (Cont'd)

	Favorable	Unfavorable
Tidal currents	Currents in the canal would reach two knots only occasionally.	
Routes of communication	Waterborne traffic operates on Lake Nicaragua and the San Juan River. The Pan American Highway runs along the divide 5 miles from the Pacific terminus.	No transisthmian road or railroad exists. There are no roads on the Atlantic side or in the interior to the upper San Juan Valley. No all-weather airfields exist nearer than San Jose and Managua.
Terrain		The heavily jungled central plain with extensive marshy areas and the low-lying Atlantic coastal plain may present problems. Maximum elevation is 1,000 feet.
Geology	Surface geology along the San Juan River indicates conditions favorable for nuclear excavation.	Knowledge of subsurface geology is limited. The critical area south of Lake Nicaragua is very uncertain. This is an area of volcanic activity.
Flood control and river diversion		Extensive flood control facilities are required for the San Juan River and streams flowing north into Lake Nicaragua and the San Juan River.
Construction features	Accessibility to the reach skirting Lake Nicaragua is relatively easy.	The level of Lake Nicaragua must be maintained. This may be critical if the alluvial material south of the lake does not remain stable under ground motion from repeated nuclear explosions.
Environmental impact		The large area of the San Carlos Plains would be cut off from access to the lake.

TABLE 13-1

CHARACTERISTICS OF ROUTE 8 NUCLEAR (Cont'd)

	Favorable	Unfavorable
Nuclear effects	Airblast effects and close-in fallout should be contained within exclusion area.	Airblast may cause damage in San Jose and Managua, and the adjacent metropolitan areas of Costa Rica and Nicaragua.
Exclusion area		Exclusion area is 150-200 miles wide and covers an area of 21,000 sq. mi. in which 675,000 people live.
Expansion possibilities	Expansion is not considered necessary.	
Local development	The region is basically undeveloped. Patches of subsistence agriculture are scattered throughout the jungle where the population density is about five people per square mile.	Ranching is found on cleared land in the divide area where the population density is about 25 people per square mile. A few small villages are located in the area between Salinas Bay and Lake Nicaragua.
Miscellaneous	This is a short route from New York to San Francisco compared to others considered.	Construction takes place in two different countries.

TABLE 13-2

CHARACTERISTICS OF ROUTE 8 CONVENTIONAL[a]

Canal dimensions	550 x 75 ft (85 ft maximum depth)
Length of land cut	169 miles
Length of approaches	7 miles
Design vessel[b]	150,000 dwt
Capacity	35,000 transits/yr (30 hrs. average TICW)
Construction time	18 years
Excavation volume	7,000,000,000 cubic yards
Excavation cost	$8,000,000,000
Other facilities	$1,200,000,000
Contingencies	$1,100,000,000
EDS&A[c]	$ 700,000,000
TOTAL CONSTRUCTION COST	$11,000,000,000
Operation and maintenance:	
Fixed costs	$50,000,000/year
Variable costs	$1,200/transit

[a]Based on a design channel with a 29-mile bypass and 1400- by 85-foot ocean approaches.

[b]A 250,000-dwt ship could transit under all expected currents.

[c]Engineering, design, supervision and administration.

	Favorable	Unfavorable
Supporting facilities	The small city of Granada on the north end of Lake Nicaragua could provide limited support.	None exist capable of providing substantial support to construction and operation of an interoceanic canal.
Harbors	Limited small boat facilities exist at San Juan del Sur.	No deep draft facilities exist in the vicinity of the route.
Harbor potential	Good potential exists in Salinas Bay.	Potential sites on the Atlantic are limited by regular coastline and marshy terrain.
Approaches/ coasts	Deep water lies close in on both coasts. Salinas Bay offers protection on the Pacific.	No protected areas exist along this stretch of the Atlantic coast.
Tidal currents	No currents over 1½ knots would occur in the canal.	

TABLE 13-2

CHARACTERISTICS OF ROUTE 8 CONVENTIONAL (Cont'd)

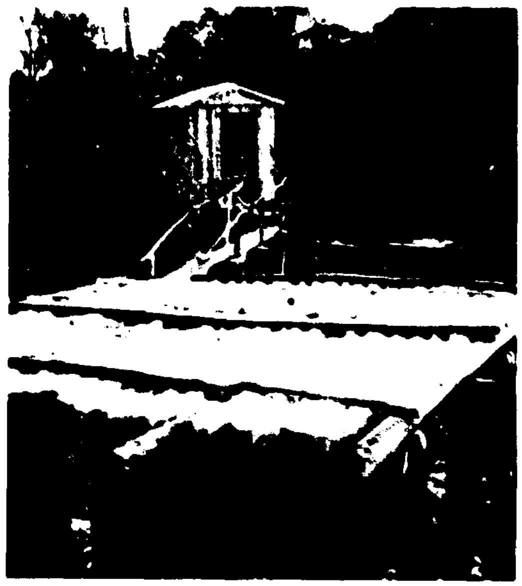
	Favorable	Unfavorable
Routes of communication	Waterborne traffic operates on Lake Nicaragua and the San Juan River. The Pan American Highway runs along the divide 5 miles from the Pacific terminus.	No transisthmian road or railroad exists. There are no roads on the Atlantic side or in the interior to the upper San Juan Valley. No all-weather airfields exist nearer than San Jose and Managua.
Terrain	Spoil disposal areas are available.	Two mountain ranges cut across the alinement. A heavily jungled central plain with extensive marshy areas inhibits access. The Atlantic coastal plain is marshy and heavily forested. Maximum elevation is 750 feet.
Geology	Surface geology along the San Juan River indicates conditions favorable for canal construction.	Knowledge of subsurface geology is limited. This is an area of volcanic activity.
Flood control and river diversion		Extensive flood control facilities are required for the San Juan River and streams flowing north into Lake Nicaragua and into the San Juan River.
Construction features	Accessibility to the reach skirting Lake Nicaragua is relatively easy.	The level of Lake Nicaragua must be maintained. This may present a problem because of the alluvial area south of the lake.
Environmental impact	A very small number of inhabitants would be displaced.	A large area of the San Carlos Plains would be cut off from access to the lake.
Expansion possibilities	No physical problems are foreseen which would not be encountered in the original construction.	Expansion would be relatively costly because of the length of the route and the deep divide cuts necessary.

TABLE 13-2

CHARACTERISTICS OF ROUTE 8 CONVENTIONAL (Cont'd)

	Favorable	Unfavorable
Local development	The region is basically undeveloped. Patches of subsistence agriculture are scattered throughout the jungle where the population density is about 5 people per square mile.	Ranching is found on cleared land in the divide area where the population density is about 25 people per square mile. A few small villages are located in the area between Salinas Bay and the lake.
Miscellaneous	This is a short route from New York to San Francisco compared to others considered.	This is a very angular alinement. Construction would take place in two different countries.

A field hydrologist measures the flow of the Atrato River.



Rain gauges and stream flow installations such as this were constructed along both Routes 17 and 25.

Geologists examine rock outcroppings along the Truando River near Teresita.

Much of the data collection activity was centered about the streams along Routes 17 and 25. Native waterborne transportation was used extensively.

CHAPTER 14

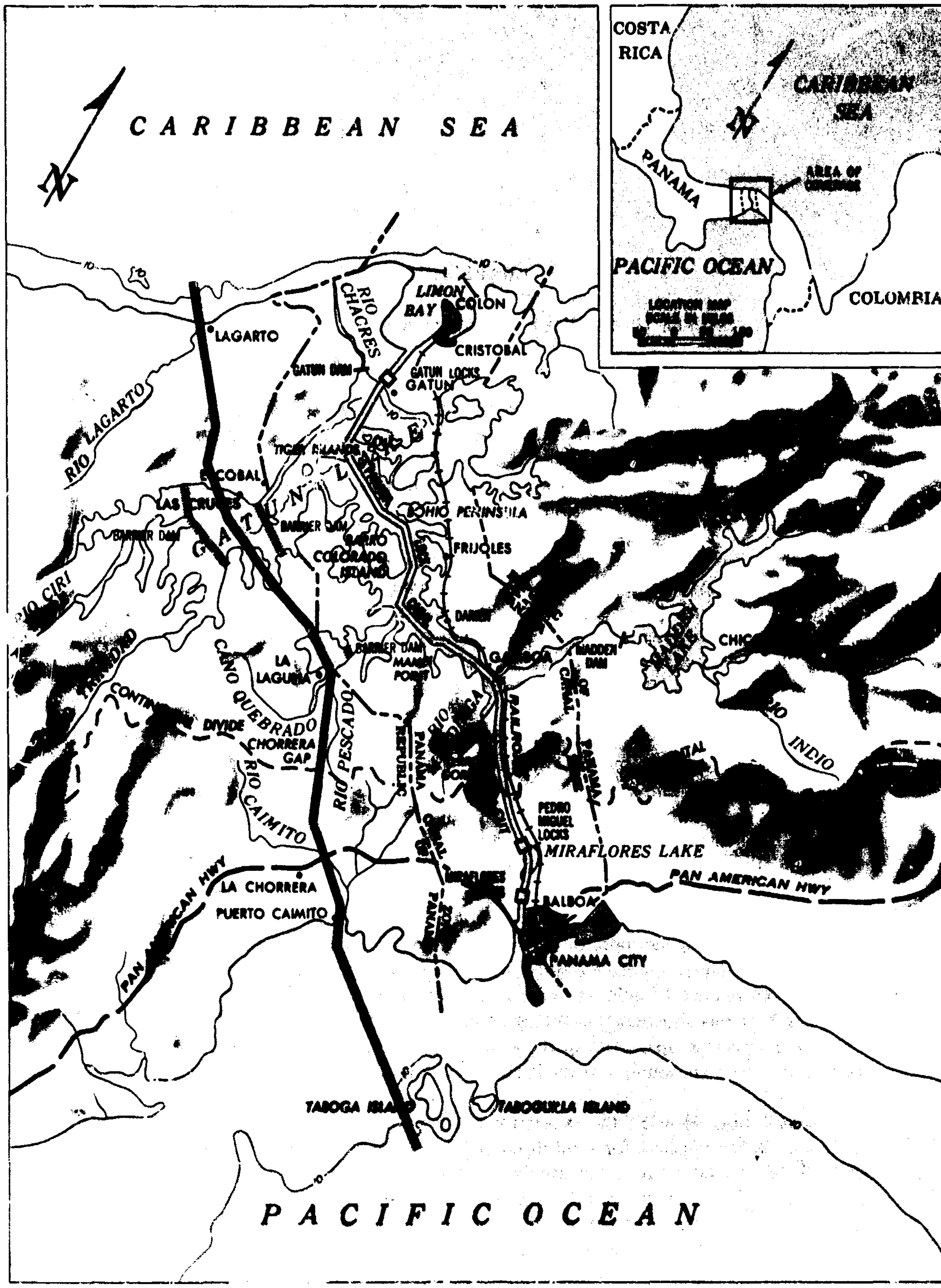
ROUTE 10–ISTHMUS OF PANAMA SEA-LEVEL CANAL

Route 10 was considered for conventional excavation only. Its proximity to the Panama Canal and built-up areas in and adjacent to the Canal Zone makes it impractical to employ nuclear excavation techniques in its construction. Various options were investigated, including several different navigation prisms, operating the canal with and without a bypass, and operating it with and without tidal checks.

Accuracy of estimates: Adequate data are available for assessing the engineering feasibility of constructing a canal along this route. Climatic, hydrologic, and geologic records for the Canal Zone area have been kept for nearly 100 years.[5] The climatic and hydrologic records generally can be extrapolated to Route 10, and onsite geologic investigations were conducted to answer specific questions relating to this route. In general, the accuracy of Route 10 estimates is considered to be good.

Route 10 trace: (See Figure 14-1.) The Pacific terminus of Route 10 is at the town of Puerto Caimito at the mouth of the Caimito River. The trace follows the river northwestward for 5 miles, crossing the Pan American Highway about 3 miles northeast of La Chorrera. It continues to the north through generally open, rolling terrain; crosses the Continental Divide through the Chorrera Gap; and parallels the Pescado River until it reaches an arm of Gatun Lake at La Laguna. Turning in a more westerly direction, the trace continues over relatively flat terrain and crosses the Trinidad Arm of Gatun Lake, to a point about 3 miles southwest of the town of Escobal. From there it runs northwesterly through low ridges which become more open toward the coast. It enters the Atlantic at the town of Lagarto. The Atlantic approach channel would be only two miles long; however, that on the Pacific would require 15 miles of underwater excavation, extending past Taboga Island. The total length of this alinement, including approaches, is 53 miles; its peak elevation is about 400 feet. Lumbering operations in the area are gradually converting the jungle into pasture land. A few farms are found near the Pacific end. A route profile is shown in Figure 14.2.

Construction: Most of the excavation along Route 10 would employ open-pit mining techniques, using rail haul for spoil disposal. Truck haul would be used at higher elevations, while dredges would excavate the approach channels and the layer of muck at the bottom of Gatun Lake. Barrier dams would maintain Gatun Lake at levels needed for operating the Panama Canal during construction, at the same time permitting excavating at controlled water levels or in the dry. Muck underlying the sites of these dams would be removed by



ROUTE 10
THE CANAL ZONE AND VICINITY

SCALE IN MILES
5 0 5 10

DEPTH IN FATHOMS

FIGURE 14-1

hydraulic dredging, after which spoil from dry excavation would be brought in to construct the embankments.

Diversion of streams on Route 10 would be relatively simple because their drainage basins are small. Most of them would be diverted into the Caribbean Sea; the Caimito River would be the only stream of consequence to discharge into the canal.

Because construction and operation of Route 10 could be supported largely from existing facilities in the Canal Zone and the metropolitan area of Panama, supporting construction requirements would be minimal. Required items would include a transisthmian highway, crossing Gatun Lake over the barrier dams; breakwaters on the Caribbean coast; a jetty on the Pacific; and a high-level bridge over the canal.

Reduction of tidal currents would require the use of tidal checks. Under a 2-knot current limitation, expansion beyond the minimum design capacity would require construction of a bypass. The alinement is well suited for a centrally-located bypass, excavated through the Gatun Lake reach.

The design channel would cost about $2.88 billion and take 14 years to construct, including 2 years for preconstruction design. Inclusion of a centrally-located bypass would raise construction costs to about $3.3 billion. Subsequent expansion of the canal's capacity by providing for two-way traffic would be relatively simple; however, it would require large cuts through high ground.

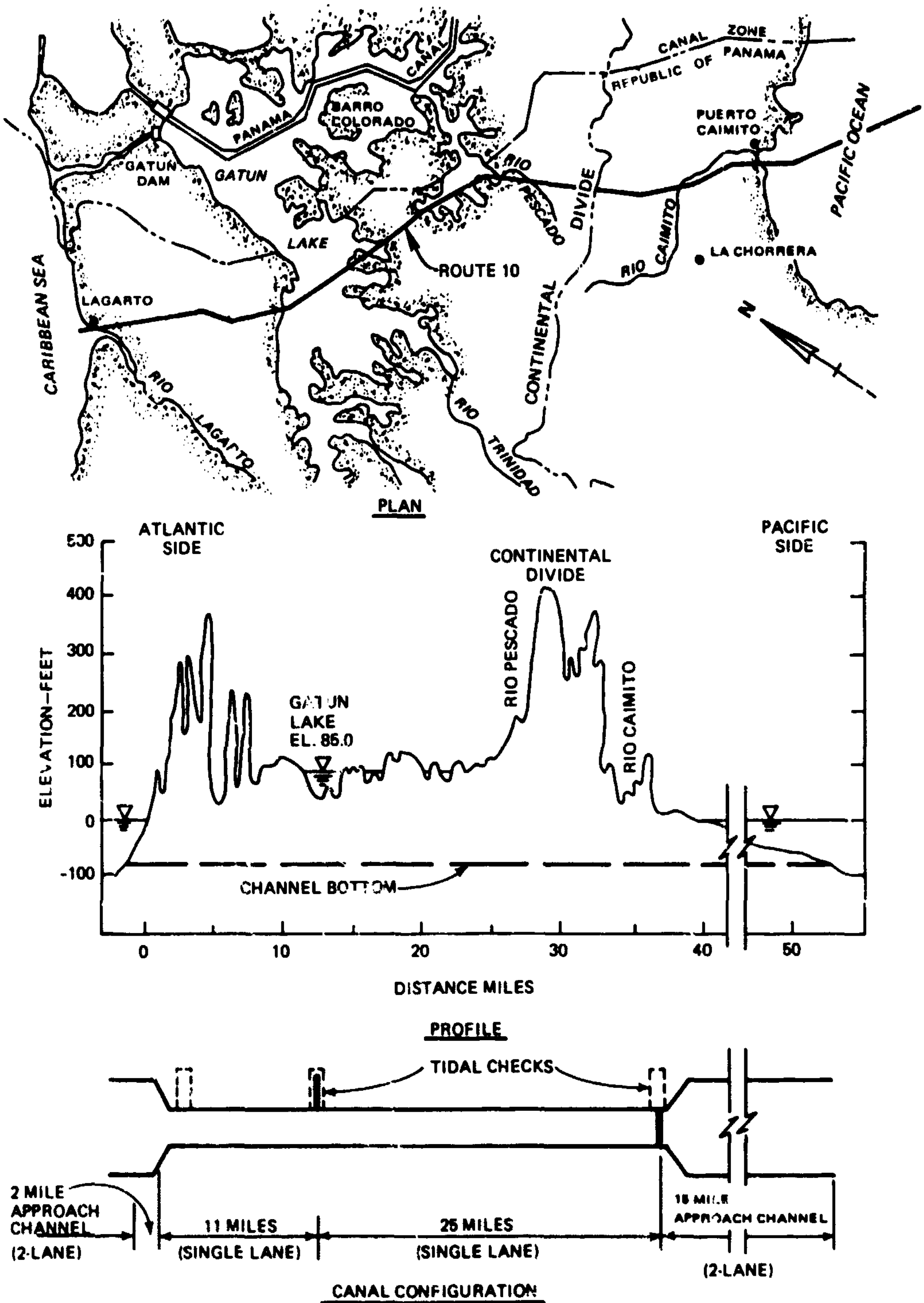
Problem areas: The most critical engineering problems involve the geology of the divide area which consists, in large part, of a hard basalt cap overlying much weaker materials. Soft rocks, similar in strength to those along the Panama Canal, are found at the depth of the navigation channel. These highly altered volcanic rocks have the undesirable properties of clay shales. Slope angles required for stability in the divide area would have to be verified through detailed investigations or modified by observation during construction.

In the design of the barrier dams, particular attention must be given to the poor foundation material in Gatun Lake and to the stability of fill material in embankments. Throughout the construction period, the lake would have to be maintained at its present level; thus, hydraulic heads exceeding 150 feet would exist when dry excavation reaches the bottom of the cut. Although failure of these dams is highly unlikely, it would have disastrous effects not only on construction of the sea-level canal but on the operation and safety of the Panama Canal as well.

The relatively short length of this alinement and the high Pacific tides would cause currents greater than 2 knots in an unrestricted channel for short periods of almost every tidal cycle. Unless experience proves that ships can transit safely in currents faster than 2 knots, continuous use of tidal checks would be required. This would limit capacity to 38,000 transits per year.

Physical conditions at either end of the alinement are not favorable to shipping. On the Atlantic side, breakwaters would be necessary to overcome the lack of natural protection. The Pacific offers more protection but the approach channel would have to be dredged about 15 miles into the Gulf of Panama.

Summary data: Characteristics of Route 10 are summarized in Table 14-1.



ROUTE 10

FIGURE 14-2

TABLE 14-1

CHARACTERISTICS OF ROUTE 10[a]

Canal dimensions	550 x 75 ft (85 ft. maximum depth)
Length of land cut	36 miles
Length of approaches	17 miles
Design vessel[b]	150,000 dwt
Capacity[c]	38,000 transits/yr (20 hrs average TICW)
Construction time	14 years (includes 2 years for design)
Excavation volume	1,870,000,000 cu. yd.
Excavation cost	$2,030,000,000
Other facilities	$ 370,000,000
Contingencies	$ 290,000,000
EDS&A[d]	$ 190,000,000
TOTAL CONSTRUCTION COST	$2,880,000,000
Operation and maintenance:	
Fixed costs	$35,000,000/year
Variable costs	$640/transit

[a]Based on a 36-mile design channel and 1400-by 85-foot ocean approaches. Additional cost of a 14-mile bypass constructed after the canal has been placed in operation would be $460,000,000, which would allow 56,000 transits a year.
[b]250,000 dwt ships could transit in favorable currents.
[c]Based on operation of tidal checks to limit current to a maximum of 2 knots.
[d]Engineering, design, supervision, and administration.

	Favorable	Unfavorable
Supporting facilities	Excellent facilities are available in the Canal Zone and in the metropolitan areas of the Republic of Panama.	
Existing harbor facilities	Excellent facilities exist in the Canal Zone in Limon Bay and at Balboa.	Existing facilities would need deepening and enlarging to hold large vessels.
Harbor potential		In the immediate area of the alinement, harbor potential is very poor on the Atlantic and poor on the Pacific.

TABLE 14-1

CHARACTERISTICS OF ROUTE 10 (Cont'd)

	Favorable	Unfavorable
Approaches/ coasts	Deep water is close in on the Atlantic side.	Approach on the Pacific is 15 miles long; approach on the Atlantic has no natural protection.
Tidal currents		Currents would exceed 2 knots on almost every tidal cycle. Continuous use of tidal gates may be required.
Routes of communication	The Canal Zone and metropolitan Panama provide excellent communications facilities, including a transisthmian railroad, transisthmian and coastwise roads, airfields and water access through the lock canal.	Gatun Lake would inhibit transisthmian overland traffic along the alinement until the barrier dams are finished. There is no transisthmian road in the immediate vicinity of the alinement.
Terrain	The alinement crosses the most cleared and even terrain of all routes except those in the Canal Zone.	Uncleared terrain is covered with thick tropical forest.
Geology	Atlantic highlands are composed of rock of intermediate quality which combines relative ease of excavation with relatively good stability.	Intercalated hard rocks and weak clayey materials in the divide cut present problems in designing stable slopes. Geologic conditions vary greatly throughout the alinement.
Flood control and river diversion	This route has the smallest tributary drainage area of any route and the smallest requirement for flood diversion facilities.	Permanent barrier dams will be required across two arms of Gatun Lake.
Construction features	The supply of common labor is good and access is relatively good.	Gatun Lake barrier dams would require very flat slopes because of questionable fill material and the consequences of dam failure. Tidal gates would be massive structures requiring special attention.

TABLE 14-1

CHARACTERISTICS OF ROUTE 10 (Cont'd)

	Favorable	Unfavorable
Environmental impact	Local impact should be minimal. The entire region is based on a canal economy.	A strip about 10 miles wide between Route 10 and the present canal would be isolated.
Expansion possibilities	Construction of a bypass would be fairly simple.	Expansion to a two-lane configuration would require cuts through higher elevations than the original alinement.
Local development	The jungle is being cleared for ranching, making access easier. Lagarto and Puerto Caimito support small fishing fleets. The general area already supports interoceanic canal commerce, and should accommodate construction of a sea-level canal with little stress.	Population density varies from 5 to 25 persons per square mile. Land is being developed now; land acquisition costs will rise.
Miscellaneous	Route 10 offers the easiest route to operate in conjunction with the present lock canal.	The barrier dams would reduce inflow to Gatun Lake which would affect supply of lockage water for the present canal during and after construction.

CHAPTER 15

ROUTE 14—PANAMA CANAL ZONE SEA-LEVEL CANAL

Route 14 was considered for conventional excavation only; its proximity to the existing canal makes nuclear excavation infeasible. There are two different alinements along this route: Route 14 Combined (14C) and Route 14 Separate (14S). Route 14C would make maximum use of the existing divide cut, thereby reducing excavation volume; while Route 14S would pass through a new and separate divide cut, thereby reducing interference with traffic in the Panama Canal. Both alternatives were investigated in detail.

Accuracy of estimates: The data available for an engineering feasibility study of Route 14 are extensive and of good quality. Climatic, hydrologic, and geologic records in the immediate area go back nearly 100 years. The Panama Canal Company has had extensive experience in dealing with slope stability problems. Consequently, estimates of excavation volumes for Route 14 are considered more accurate than those of other routes.

Route 14C trace: (See Figure 15-1.) On the Pacific side, Route 14C coincides with the approaches to the present lock canal until it reaches the Pacific Third Locks cut where it changes direction slightly to pass southwest of Miraflores and Pedro Miguel Locks. Following generally the alinement of the Panama Canal northeast of Cerro Gordo, it continues toward Gatun Lake, keeping southwest of the present canal until it reaches the Darien peninsula. Turning slightly northward then, it passes Barro Colorado Island on the east, touching the end of Bohio Peninsula. There the trace turns to the north across Gatun Lake and enters the Atlantic Third Locks cut. From that point, it follows the present canal into the Caribbean. The Pacific approach channel is 13 miles long; that on the Atlantic is 8. The total length of this alinement, including approaches, is 54 miles; the highest elevation along the centerline is about 400 feet.

Route 14S trace: (See Figure 15-1.) The trace of Route 14S is identical to that of Route 14C, except for an 8-mile reach through the Continental Divide. The routes diverge at the Pacific Third Locks cut. Route 14S runs ½ to 1 mile southwest of Route 14C, passing north of Cerro Gordo and rejoining Route 14C east of the Mandinga River. Its length, including approaches is 54 miles; its peak elevation along the centerline is 450 feet. Figures 15-2 and 15-3 show centerline profiles of the routes.

Construction: Each Route 14 option would require two principal excavation efforts: dredging across Gatun Lake and cutting through the divide. Across Gatun Lake, where the alinements coincide, deep dredging techniques would be employed, using hydraulic dredges

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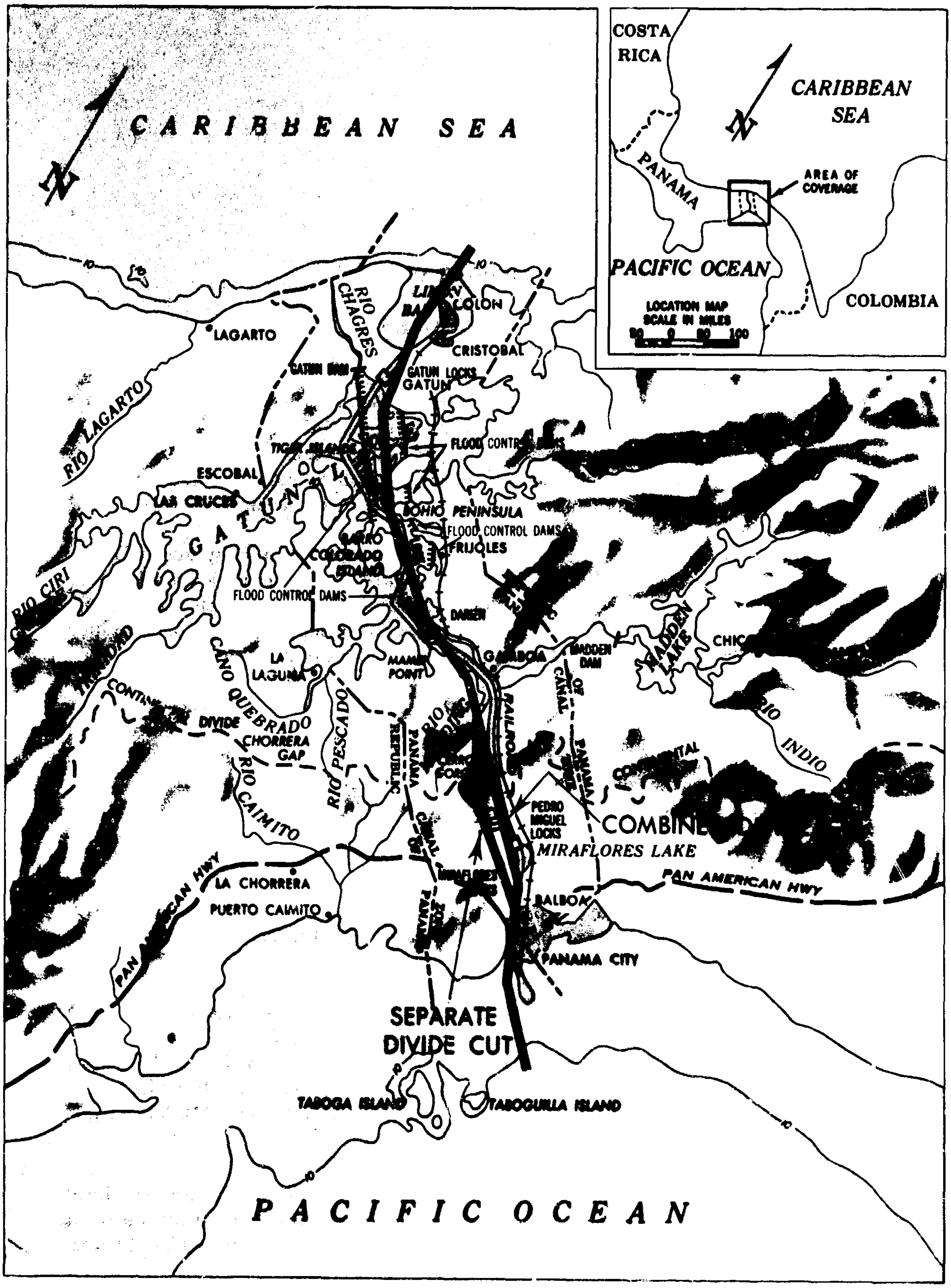


ROUTE 14
THE CANAL ZONE AND VICINITY

SCALE IN MILES
5 0 5 10
DEPTH IN FATHOMS

FIGURE 15-1

for soft muck, dipper dredges for rock at shallow depths and barge-mounted draglines for rock below elevation +15 feet. Construction plugs would keep the lake at its present level (+85 feet) to sustain operations in the Panama Canal while this work is being accomplished. Scows would move excavated material to underwater spoil areas in the lake. Much of this material would be used as fill in the permanent flood control dams on either side of the alinement. Where practicable, shovels and large dump trucks would be employed to excavate the higher elevations. As the final step of the construction phase, Gatun Lake would be drawn down and the sea-level canal placed in operation. Pools behind the flood control dams would be maintained at an elevation of 55 feet.

Through the Route 14C divide reach, material above the level of Gatun Lake would be excavated in the dry using shovels, with truck and rail haul to disposal areas. This would remove about 70 percent of the divide material. The dredging techniques employed in Gatun Lake also would be used to excavate the remaining material, with spoil hauled in scows to the lake. Along the Route 14S alinement, about 80 percent of the material could be removed by open-pit mining/rail haul methods; the remainder would be excavated by dipper dredges and hauled in scows to Gatun Lake and the Pacific Ocean.

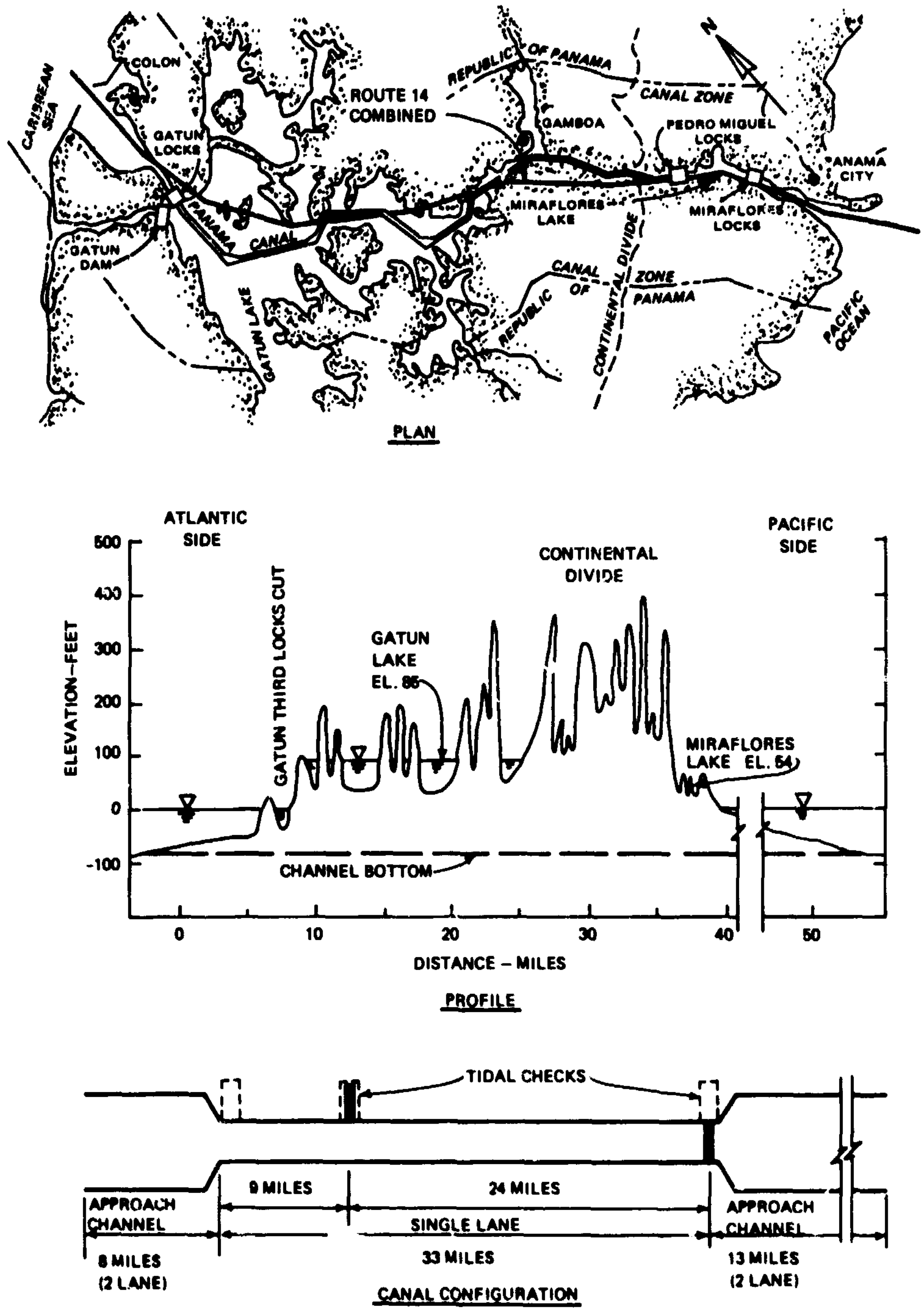
Except for the Chagres River on Route 14C, flood control and stream diversion on either route involves no serious problems. The two major reservoirs remaining in the Gatun Lake basin would be discharged into the Caribbean, one through the spillway at Gatun, the other through a new outlet east of Cristobal. The Chagres River would be diverted to the Pacific through the existing canal if Route 14S were built; however, if the canal lay along Route 14C, the flow of the Chagres would have to be carried in the navigation channel. Smaller streams in either case would be channeled into the canal through inlet structures.

Costs of facilities to support construction and operation of Routes 14C and 14S are affected by the existing state of development within the Canal Zone. The necessary harbors, communications, and utilities already exist and can be used as they are. Other facilities such as channels and anchorages might have to be modified. In general, however, mobilization for construction on this route would be easier than on any other route.

The minimum project for either Route 14 alinement would have two-lane (1,400 feet) approaches and a 33-mile single-lane section cut to design channel dimensions. Tidal checks would be installed to maintain current velocities at 2 knots or less. This configuration would provide more than the initial design capacity.

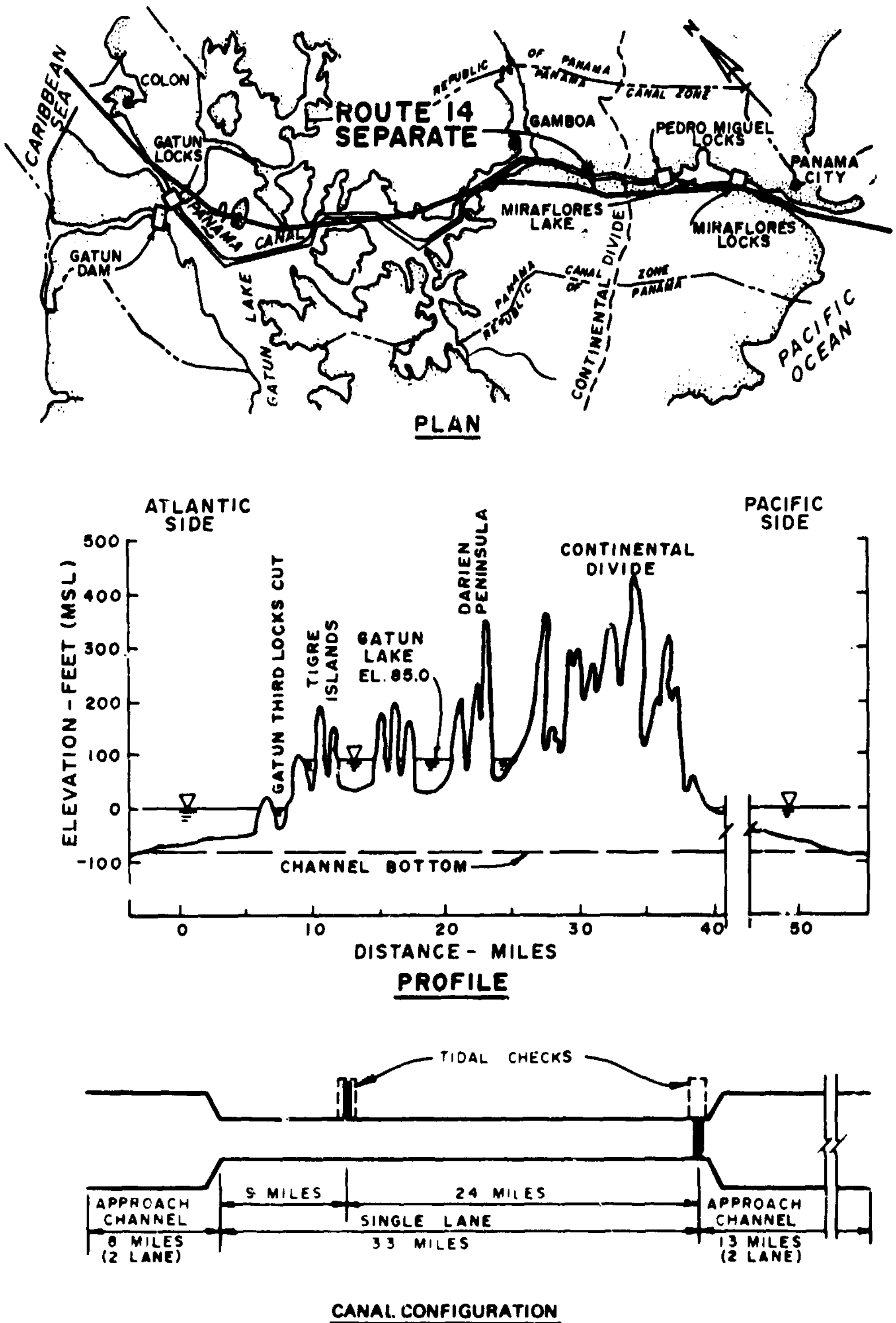
On Route 14C such a canal would cost approximately $2.93 billion and would take about 13 years to design and construct. Along Route 14S its cost would be approximately $3.04 billion; it would require nearly 16 years to complete. In either case, transiting capacity could be increased by extending the two-lane Atlantic approach 9 miles across Gatun Lake at an additional cost of about $430 million.

Problem areas: The geology of the divide reach is known to be poorly suited for deep cuts. Route 14S was proposed as a means of lessening the possibility of slides blocking the Panama Canal for long periods during construction of a sea-level canal. The risk of severe blockage would be reduced at the price of greater excavation volumes and longer construction time. Even so, there would remain some risk of major slides into the present canal.



ROUTE 14 COMBINED

FIGURE 15-2



ROUTE 14 SEPARATE

FIGURE 15-3

Conversion of the canal's operations from locks to sea level would be complex and difficult and would take between 1 and 3 months, during which time all Panama Canal traffic would stop. This transition would require removing the construction plugs maintaining Gatun Lake, thus draining the canal to sea level and lowering the remainder of Gatun Lake to approximately elevation 55 feet. The rapid drawdown of water levels would develop seepage pressures which might lead to serious slope stability problems, particularly on Route 14C.

The poor foundation material underlying the flood control dams and the possible instability of their fill material would be countered by making them massive and by building them on a blanket of select material. Construction of these dams in water depths up to 80 feet would demand special care. Because the Gatun Lake reach would be excavated by dredging, the hydraulic head on these dams would not be as great as that developed on the Route 10 barrier dams.

Strict traffic control would be required during construction on both Route 14 alinements, but particularly on Route 14C where the sea-level canal would generally follow the existing canal through the divide. Bottom dump scows would ply between dredging areas in the cut and spoil areas in Gatun Lake. The proposed alinements would cross the present navigation channel twice in the lake and would coincide with the existing canal in both approaches to Gatun Lake. Consequently, construction traffic would present hazards to and interfere with transiting vessels at a time when the Panama Canal would be approaching the limit of its traffic capacity.

The topography of Route 14 does not lend itself readily to a bypass. However, increased capacity could be achieved by widening the channel in from the Atlantic Coast and across Gatun Lake to two lanes and reducing the length of the single-lane section.

Currents would exceed 2 knots on almost every tidal cycle and would exceed 4 knots on 35 percent of the cycles. Unless experience proves that ships can transit safely in currents faster than 2 knots, continuous use of tidal checks would be required.

Summary data: The characteristics of Routes 14C and 14S are summarized in Tables 15-1 and 15-2, respectively.

TABLE 15-1

CHARACTERISTICS OF ROUTE 14C[a]

Canal dimensions	550 x 75 ft (85 ft maximum depth)
Length of land cut	33 miles
Length of approaches	21 miles
Design vessel[b]	150,000 dwt
Capacity[c]	39,000 transits/yr (20 hrs average TICW)
Construction time	13 years (includes 2 years for design)
Excavation volume	1,600,000,000 cubic yards
Excavation cost	$2,120,000,000
Other facilities	$ 330,000,000
Contingencies	$ 290,000,000
EDS&A[d]	$ 190,000,000
TOTAL CONSTRUCTION COST	$2,930,000,000
Operation and maintenance:	
Fixed costs	$33,000,000/year
Variable costs	$640/transit

[a]Based on a 33-mile design channel and 1400- by 85-foot approaches. Reducing the single lane length to 24 miles would cost $430,000,000 more and increase transit capacity to 55,000/year.

[b]250,000 dwt ships could transit in favorable currents.

[c]Based on operation of tidal checks to limit current to a maximum of 2 knots.

[d]Engineering, design, supervision and administration.

	Favorable	Unfavorable
Supporting facilities	Excellent facilities exist in the Canal Zone and in the metropolitan areas of the Republic of Panama.	
Existing harbor facilities	Excellent facilities exist in the Canal Zone in Limon Bay and at Balboa.	Existing facilities would need deepening and enlargement to hold large vessels.
Harbor potential	Low-lying areas along adjacent coasts could be dredged to provide more anchorage and berthing.	All protected areas available for expansion require dredging.
Approaches/ coasts		Approaches are relatively long.

TABLE 15-1

CHARACTERISTICS OF ROUTE 14C (Cont'd)

	Favorable	Unfavorable
Tidal currents		Currents would exceed 2 knots on almost every tidal cycle and would exceed 4 knots on 35% of the cycles. Continuous use of tidal gates is likely.
Routes of communication	The Canal Zone and metropolitan Panama provide excellent communications facilities, including a transisthmian railroad, transisthmian and coastwise roads, airfields and water access through the lock canal.	
Terrain	The alinement generally follows the lock canal alinement, with the benefit of low elevations and cleared land. Gatun Lake is the dominant feature.	
Geology	Geology along Route 14 is the best known of all the routes.	Known areas of weak rock would require flat slopes and extreme care to avoid risks of slides blocking the canal. Flood control dams across Gatun Lake would rest on poor material.
Flood control and river diversion		Sixteen miles of massive flood control dams would be required in Gatun Lake and lowering of the the lake level would be required during conversion. Chagres River flows would have to drain into the sea-level canal.
Local development	Land development in the construction area has been restricted. The region already supports interoceanic canal commerce, and should accommodate construction of a sea-level canal with little stress.	

TABLE 15-1

CHARACTERISTICS OF ROUTE 14C (Cont'd)

	Favorable	Unfavorable
Construction features	Access is relatively easy. The supply of common labor is plentiful.	A slide which could block canal traffic for a long time is possible, especially during conversion. This problem is more critical on Route 14C than 14S. Tight traffic control is essential to minimize interference between dumping scows and canal traffic. This problem is also more serious on Route 14C. Loss of Gatun Lake must not be risked. Tidal gates would be massive structures requiring special attention.
Environmental impact	More land would be opened for possible development by lowering the lake level. The tropical environment would soon repair damage caused by lake lowering.	Spoil disposal in Gatun Lake and lowering of the lake level will adversely affect the lake's ecology.
Expansion possibilities	Shortening the length of the one-way reach would be fairly simple.	Expansion to a 2-lane configuration would require deep cuts through areas of known instability.
Miscellaneous	Construction would take place within the Canal Zone.	Construction of this route would eliminate permanently the present lock canal as an operable alternate route.

TABLE 15-2

CHARACTERISTICS OF ROUTE 14S[a]

Canal dimensions	550 x 75 ft (85 ft maximum depth)
Length of land cut	33 miles
Length of approaches	21 miles
Design vessel[b]	150,000 dwt
Capacity[c]	39,000 transits/yr (20 hrs average TICW)
Construction time	16 years (includes 2 years for design)
Excavation volume	1,950,000,000 cubic yards
Excavation cost	$2,210,000,000
Other facilities	$ 330,000,000
Contingencies	$ 300,000,000
EDS&A[d]	$ 200,000,000
TOTAL CONSTRUCTION COST	$3,040,000,000
Operation and maintenance:	
Fixed costs	$34,000,000/year
Variable costs	$640/transit

[a]Based on a 33-mile design channel and 1400- by 85-foot approaches. Reducing the single lane length to 24 miles would cost $430,000,000 more and increase transit capacity to 55,000/year.

[b]250,000 dwt ships could transit in favorable currents.

[c]Based on operation of tidal checks to limit current to a maximum of 2 knots.

[d]Engineering, design, supervision and administration.

	Favorable	Unfavorable
Supporting facilities	Excellent facilities exist in the Canal Zone and in the metropolitan areas of the Republic of Panama.	
Existing harbor facilities	Excellent facilities exist in the Canal Zone in Limon Bay and at Balboa.	Existing facilities would need deepening and enlargement to hold larger vessels.
Harbor potential	Low-lying areas along adjacent coasts could be dredged to provide more anchorage and berthing.	All protected areas available for expansion require dredging.
Approaches/ coasts		Approaches are relatively long.

TABLE 15-2

CHARACTERISTICS OF ROUTE 14S (Cont'd)

	Favorable	Unfavorable
Tidal currents		Currents would exceed 2 knots on almost every tidal cycle and would exceed 4 knots on 35% of the cycles. Continuous use of tidal gates is likely.
Routes of communication	The Canal Zone and metropolitan Panama provide excellent communications facilities, including a transisthmian railroad, transisthmian and coastwise roads, airfields and water access through the lock canal.	
Terrain	The alinement generally follows the lock canal alinement except through the divide reach. Elevations are generally low. The land is cleared and mostly unused. Gatun Lake is the dominant feature.	
Geology	Geology along Route 14 is the best known of all the routes. The separate divide cut is not as well known as the rest of the route.	Known areas of weak rock would require flat slopes and care to avoid risk of slides blocking the canal. Flood control dams across Gatun Lake would rest on poor materials.
Flood control and river diversion	Stream diversion requirements are minimal.	Sixteen miles of massive flood control dams would be required in Gatun Lake and lowering of the lake would be required during conversion.
Local development	Land development in the construction area has been restricted. The region already supports interoceanic canal commerce, and should accommodate construction of a sea-level canal with little stress.	

TABLE 15-2

CHARACTERISTICS OF ROUTE 14S (Cont'd)

	Favorable	Unfavorable
Construction problems	Access is relatively easy. The supply of common labor is plentiful.	A slide which could block canal traffic for a long time is possible. Tight traffic control is necessary to minimize interference between dumping scows and canal traffic. Loss of Gatun Lake must not be risked. Tidal gates would be massive structures requiring special attention.
Environmental impact	More land would be opened for possible development by lowering of the lake level. The tropical environment would soon repair damage caused by lake lowering. There would be less spoil disposal in Gatun Lake for Route 14S than for Route 14C.	Spoil disposal in Gatun Lake and lowering of the lake level will adversely affect the lake's ecology.
Expansion possibilities		The topography does not lend itself to incremental expansion.
Miscellaneous	Construction would take place within the Canal Zone.	Construction of this route would eliminate permanently the present lock canal as an operable alternate route. The Route 14 options pose a major hindrance to operations of the Panama Canal during construction.

CHAPTER 16

ROUTE 17 – DARIEN ISTHMUS SEA-LEVEL CANAL

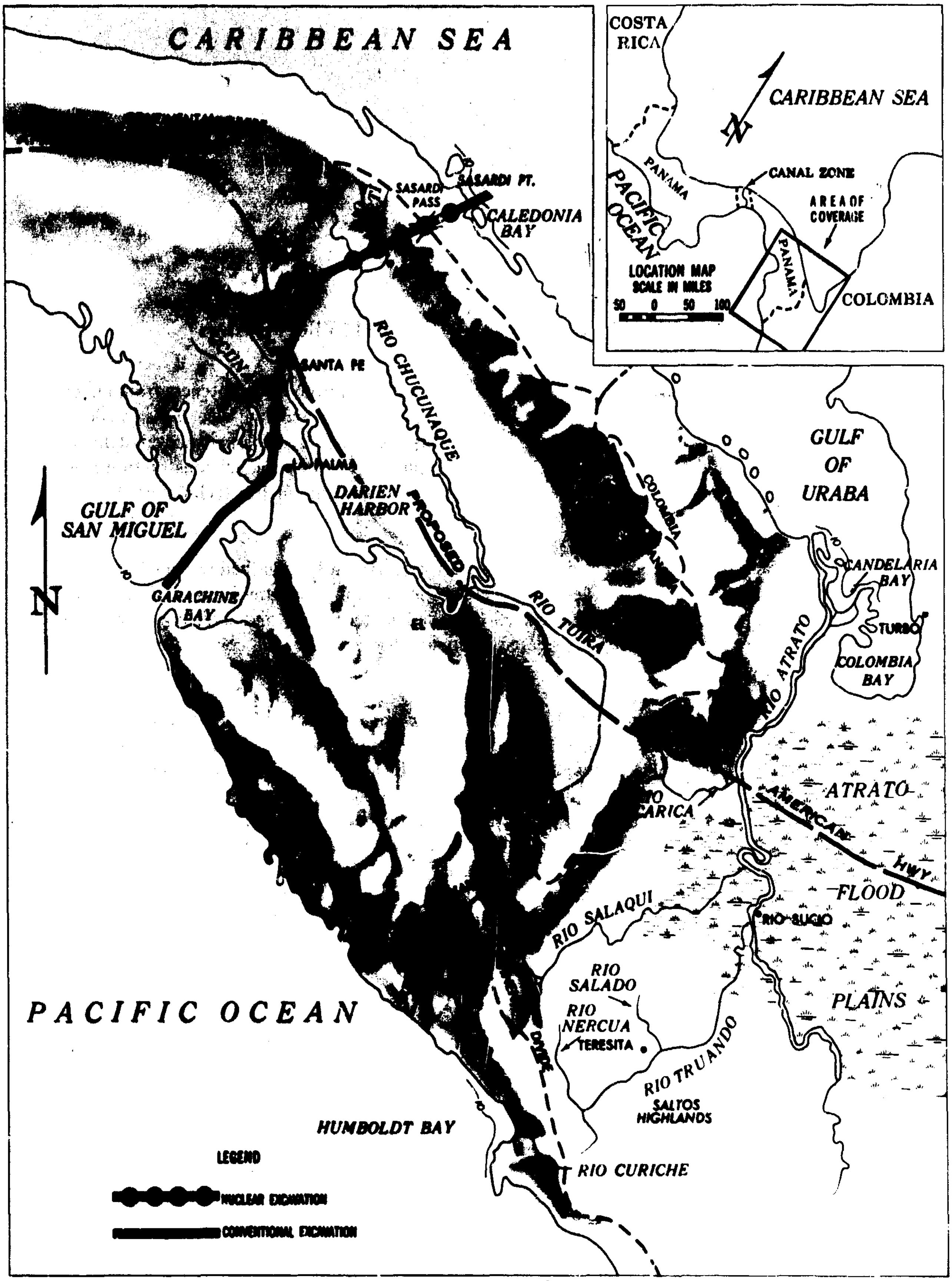
Route 17 was considered originally as an all-nuclear option. Its remoteness from major population centers, together with its relatively short length and low elevations, made it appear well suited for nuclear excavation. Adverse geologic conditions discovered in its central reach during this study have caused reformulation of the original construction plan to provide for excavation by a combination of conventional and nuclear techniques. A more detailed discussion of Route 17 is presented in Appendix 12.

Accuracy of estimates: The investigative efforts previously described provided the data needed to support conceptual designs and cost estimates for this route. In spite of a number of deficiencies in this data base (lack of extended meteorologic and hydrologic records) estimates for this route are considered adequate for purposes of comparison between nuclear excavated routes.

Route 17 trace: (See Figure 16-1). The Pacific approach to Route 17 begins 28 miles from shore, in the Gulf of San Miguel. From the shoreline, the alinement runs north approximately 12 miles through the Pacific Hills. At the Sabana River it turns northeastward and traverses the combined lowlands of the Sabana and Chucunaque valleys for 20 miles. Turning further east, the alinement proceeds up the valley of the Morti River, crosses the Continental Divide through Sasardi Pass and continues across the narrow Atlantic coastal plain to the shoreline. It terminates in deep water approximately 2 miles offshore just east of Sasardi Point. The total length of Route 17, including approaches, is 79 miles; the highest elevation along the centerline is approximately 1,000 feet. The region it traverses is heavily forested and largely undeveloped. The centerline profile of the alinement is shown in Figure 16-2.

Construction: Excavation plans for Route 17 call for the use of nuclear explosives through the Pacific Hills and the Continental Divide. The presence of weak clay shales in the Chucunaque Valley would require cuts with extremely flat side slopes, thus precluding the use of nuclear excavation. This 20-mile reach, at an average elevation of slightly less than 200 feet, would require conventional excavation of about 1.6 billion cubic yards, accomplished primarily by an open-pit mining/rail haul system.

In addition to excavating the main channel through the higher elevations, nuclear explosives would be used to open several river diversion channels. The nuclear excavation program would involve about 250 explosives ranging in yields from 100 kilotons to 3 megatons, with a total yield of approximately 120 megatons. They would be detonated in



ROUTE 17

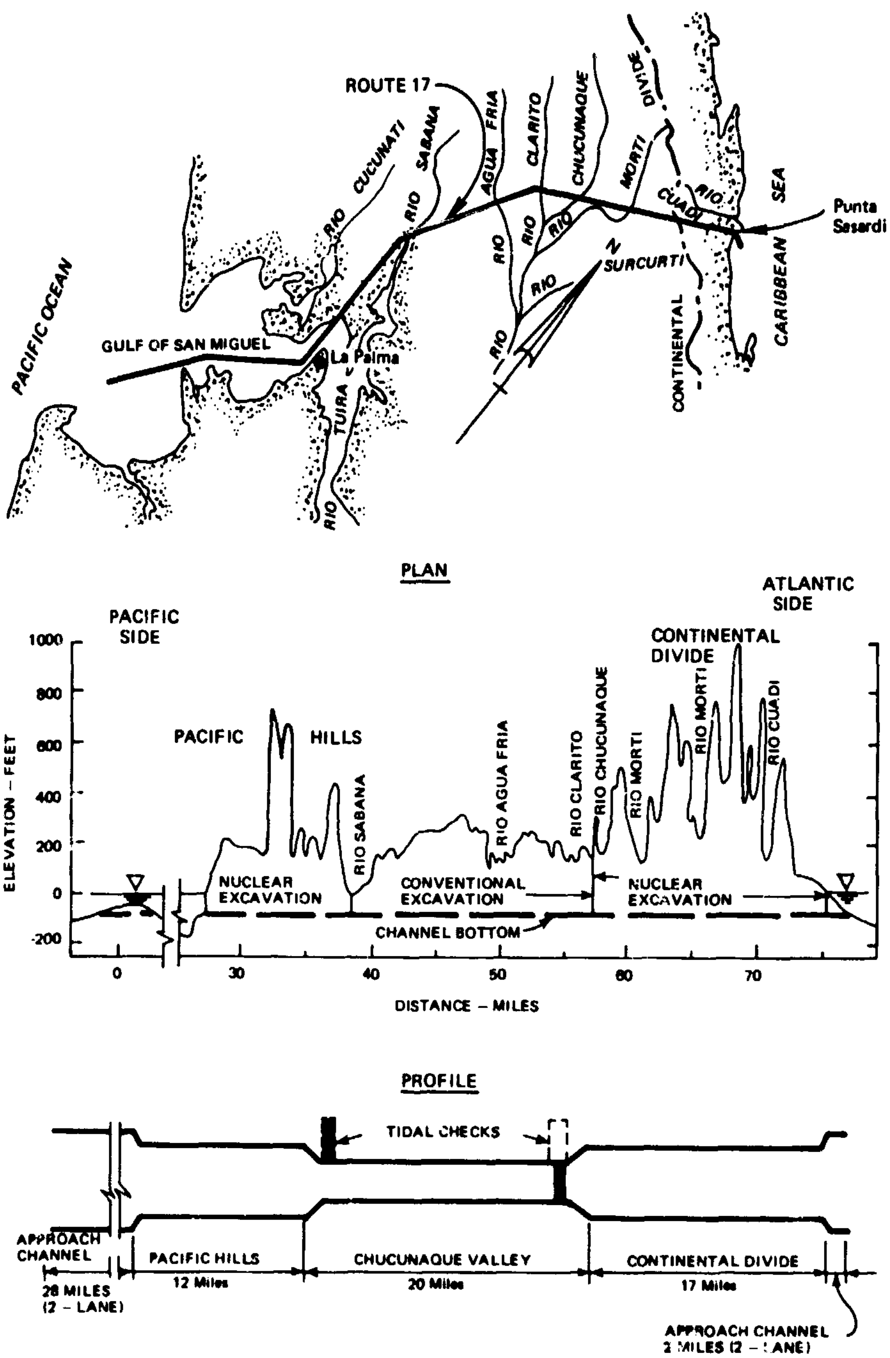
PANAMA-COLOMBIA BORDER AREA

SCALE IN MILES

5 0 5 10 15 20 25 30 35

DEPTHS IN FATHOMS

FIGURE 16-1



CANAL CONFIGURATION

ROUTE 17

FIGURE 16-2

about 30 groups with yields ranging from 800 kilotons to 11 megatons. Detonations would be scheduled when meteorological conditions ensure that hazardous fallout would be contained within the exclusion area and that any risk of long-range airblast damage would be minimized. There would be two series, or passes, of detonations, the first lasting 13 months. This would be followed by second pass emplacement construction which would require 16 months. Five more months would be required for the second pass. Conventional excavation and construction of permanent facilities would begin after the second pass detonations.

Route 17 would intercept the Sabana River and the upper reaches of the Chucunaque. The Chucunaque would enter the canal through an inlet excavated by nuclear means, with a spillway to dissipate the energy of a drop of approximately 100 feet. The Sabina River would enter the canal at about sea level through a transition structure.

Because of the lack of development in the Darien region, all facilities required to support construction and operation of the canal would have to be provided. These would include a transisthmian highway and other roads, harbor facilities, an all-weather airfield, administrative and residential facilities, and a ferry crossing of the canal for the Pan American Highway.

Design and construction of a sea-level canal along Route 17, as described above, would require about 16 years and cost about $3 billion.

Problem areas: The most significant problem area surrounding Route 17 is the present uncertainty regarding the feasibility of nuclear excavation.

The clay shales encountered through the Chucunaque Valley present serious slope stability problems, even if excavated by conventional means.

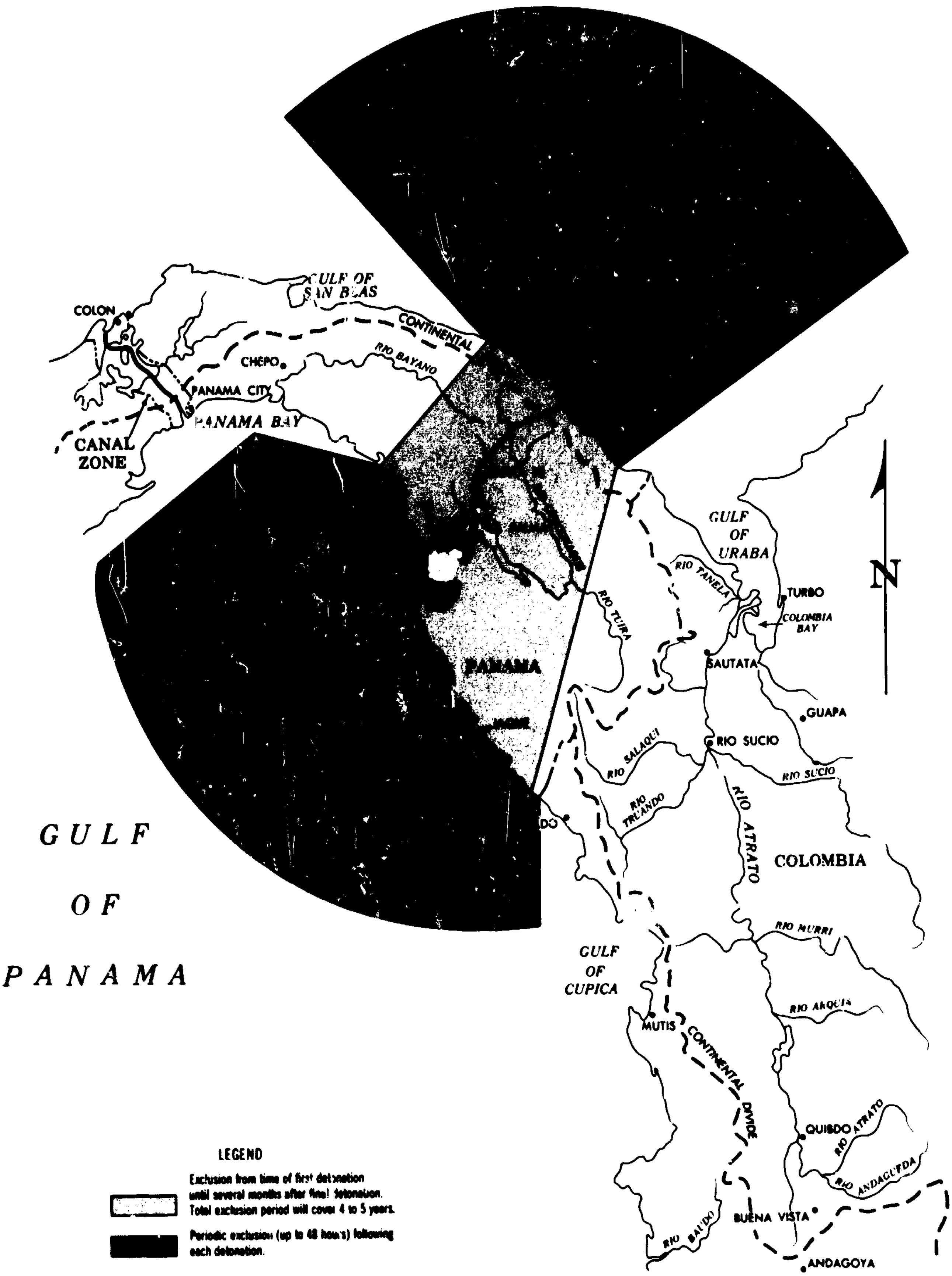
Tidal currents would attain a maximum velocity of 6.8 knots if tidal checks were not used. Currents greater than 2 knots would occur at some time during all tidal cycles, necessitating continual use of tidal checks.

The economy of the Darien region is inadequate to support construction of a sea-level canal. The area is covered with heavy jungle and almost completely undeveloped. On the Pacific side, Darien Harbor could be developed into a suitable facility; but early permanent buildup of this area would be impracticable because it lies well within the nuclear exclusion area. Adequate port facilities would be more difficult to construct along the less protected Atlantic coast. The jungle terrain and heavy rainfall are not conducive to road construction. Access to the alinement would be very limited until roads, ports and airfields were built. Locally available skilled labor does not exist and common labor is in short supply.

A land exclusion area (Figure 16-3) would have to be evacuated prior to any nuclear detonation and kept clear, perhaps for as long as 1 year after the last detonation. It would include an area of 6,500 square miles from which approximately 43,000 inhabitants would have to be evacuated. Radiological surveys would be conducted continuously during and after detonation to determine when the area could be reoccupied. In some areas re-entry could begin shortly after the last detonation; however, it would probably be more practical to re-open the entire exclusion area, except for the immediate vicinity of the craters, at one time 6 to 12 months after the last detonation. The exclusion area over the ocean would be operative only for a short time, 1 to 2 days after each detonation.

In Panama City and other outlying built-up areas, there may be minor damage from ground motion which would be generated by some of the larger nuclear detonations.

Summary data: The characteristics of Route 17 are summarized in Table 16-1.



ROUTE 17 NUCLEAR EXCLUSION AREA

SCALE IN MILES
25 0 25 50

FIGURE 16-3

TABLE 16-1

CHARACTERISTICS OF ROUTE 17[a]

Canal dimensions	See note a.
Length of land cut	49 miles
Length of approaches	30 miles
Design vessel[b]	150,000 dwt
Capacity[c]	42,000 transits/yr (20 hrs average TICW)
Construction time	16 years
Conventional excavation volume	1,600,000,000 cubic yards
Conventional excavation cost	$1,560,000,000
Nuclear excavation cost	$ 220,000,000
Other facilities	$ 730,000,000
Contingencies	$ 350,000,000
EDS&A[d]	$ 200,000,000
TOTAL CONSTRUCTION COST	$3,060,000,000
Operation and maintenance:	
Fixed costs	$35,000,000/year
Variable costs	$640/transit

[a]Based on a 20-mile long, centrally located, design channel; 1,000-foot wide nuclear excavated sections at either end, and 1,400-foot wide ocean approaches.

[b]250,000 dwt ships could transit in favorable currents.

[c]Based on continuous operation of tidal checks to limit current to a maximum of 2 knots.

[d]Engineering, design, supervision, and administration.

	Favorable	Unfavorable
Supporting facilities		None exists capable of supporting construction and operation of an interoceanic canal.
Harbors	Limited berthing for small craft exists in Darien Harbor at La Palma.	None exists capable of handling deep draft vessels.
Harbor potential	Good potential exists on the Pacific coast for deep draft vessels, after dredging.	The Atlantic coast offers only limited protection for harbors.
Approaches/ coasts	Deep water is close in on the Atlantic. A large protected area is available on the Pacific.	Intermittent sections of the 28-mile approach channel through the Gulf of San Miguel would need dredging.

TABLE 16-1

CHARACTERISTICS OF ROUTE 17 (Cont'd)

	Favorable	Unfavorable
Tidal currents		Currents are the highest of all routes. Tidal checks would be in continuous use.
Routes of communication		Access is the poorest of all routes. These are no trans-isthmian or coastal routes of communications and no all-weather airfields.
Terrain	Spoil disposal areas are readily available on this route.	Two mountain ranges must be traversed. The entire route is heavily jungled. Maximum elevation is about 1,000 feet.
Geology	Subsurface investigation indicates materials at higher elevations probably would be amenable to nuclear excavation.	Subsurface geologic information is limited compared to Routes 10 and 14. Clay shale materials in the Chucunaque Valley would require flat side slopes throughout a 20-mile reach of the canal.
Flood control and river diversion		The flood control structures must accommodate the large volume of high silt content runoff from the Chucunaque River and its major tributaries.
Construction features		Most conventional construction would have to be postponed until nuclear excavation is completed. The clay shale in the Chucunaque Valley would require very flat side slopes and may cause slope stability problems during construction. The local labor supply is extremely limited. Tidal gates would be massive structures requiring special attention.

TABLE 16-1

CHARACTERISTICS OF ROUTE 17 (Cont'd)

	Favorable	Unfavorable
Environmental impact		Population centers exist within the exclusion area at La Palma, the Pearl Islands and the Cuna and Choco Indian settlements.
Nuclear effects	Direct airblast effects and potentially harmful fallout would be contained within the exclusion area.	Effects of ground motion might cause minor damage in Panama City.
Exclusion area		The exclusion area is about 100 miles wide and covers a land area of about 6,500 square miles in which approximately 43,000 persons live.
Expansion possibilities	Nuclear excavated sections would not need to be expanded to carry 2-lane traffic.	Expansion of the conventionally excavated section in the Chucunaque Valley would be costly because of the relatively high average elevation.
Local development	The population density is only 6 persons per square mile. Development is minimal. Inhabitants are engaged in fishing on the Pacific coast. A ranching economy is just beginning.	Highly communal Cuna Indians living on islands off the Atlantic coast must be evacuated. Lack of development requires all support for construction to come from outside the Darien region.

CHAPTER 17

ROUTE 23 – PANAMA-COLOMBIA SEA-LEVEL CANAL

Route 23 was considered for excavation by either conventional or nuclear means or by a combination of both techniques. Its remote location makes this route appear well suited for nuclear excavation; its low divide elevation is favorable for conventional excavation. A more detailed discussion of Route 23 is contained in Appendix 14.

Accuracy of estimates: The data base for Route 23 is among the poorest for the routes considered in this study. Geographic, geologic, hydrologic, and topographic data for the Tuira Valley and the adjacent divide region are extremely limited. Since consideration of this route was proposed after field investigations in the Isthmus had been completed, no new information was gathered to supplement existing data which are extremely meager (e.g., estimates of the minimum divide elevation range from 330 to 550 feet).* Subsurface geologic information required for reliable estimates of nuclear cratering effects, slope stability, and excavation costs is not available. Field data were extrapolated from Routes 17 and 25 to estimate construction costs of the Route 23 alternatives. Because of the weakness of its data base, analysis of this route was not carried to the same degree of refinement as that achieved for other routes.

Route 23 trace: (See Figure 17-1). The Pacific approach of Route 23 begins 24 miles from shore in the Gulf of San Miguel. To avoid excessive angularity as it turns into Darien Harbor, the trace cuts through the narrow peninsula on which La Palma is situated. It then follows the Tuira Valley southeastward past El Real. The terrain in this reach is low, swampy and densely overgrown. As it continues southeastward, the trace generally parallels the proposed route for the Pan American Highway, gradually rising until it reaches the divide pass at about 450 feet elevation. In this area, the terrain is heavily forested and sparsely populated. Beyond the divide, the trace follows the Cacarica River as it descends into the alluvial flood plain of the Atrato River near Sautata. From that point it parallels the low-lying Atrato to its mouth in Candelaria Bay, 3 miles from deep water. The total length of the route, including approaches, is 146 miles. Although there are several small towns and villages along Route 23, the region is essentially undeveloped. The Atrato Valley supports some sawmill operations, and limited subsistence agriculture is conducted in the Tuira Valley. Figure 17-2 shows the assumed profile of Route 23.

*Recent data furnished by Dr. Mauricio Obregon, President of the Choco Development Corporation, Bogota, Colombia, supports elevation 450 feet used to prepare estimates for this study.

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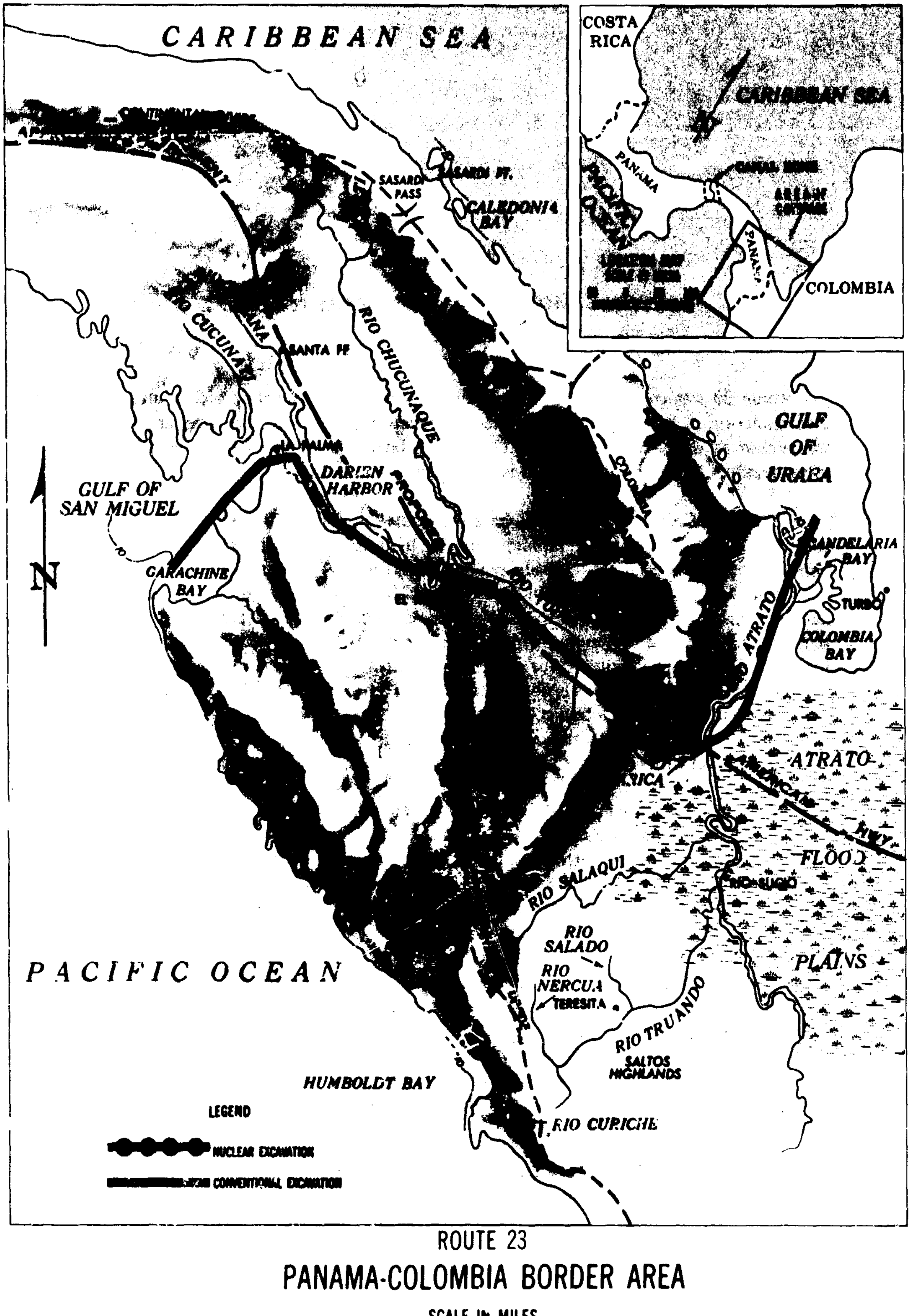


ROUTE 23

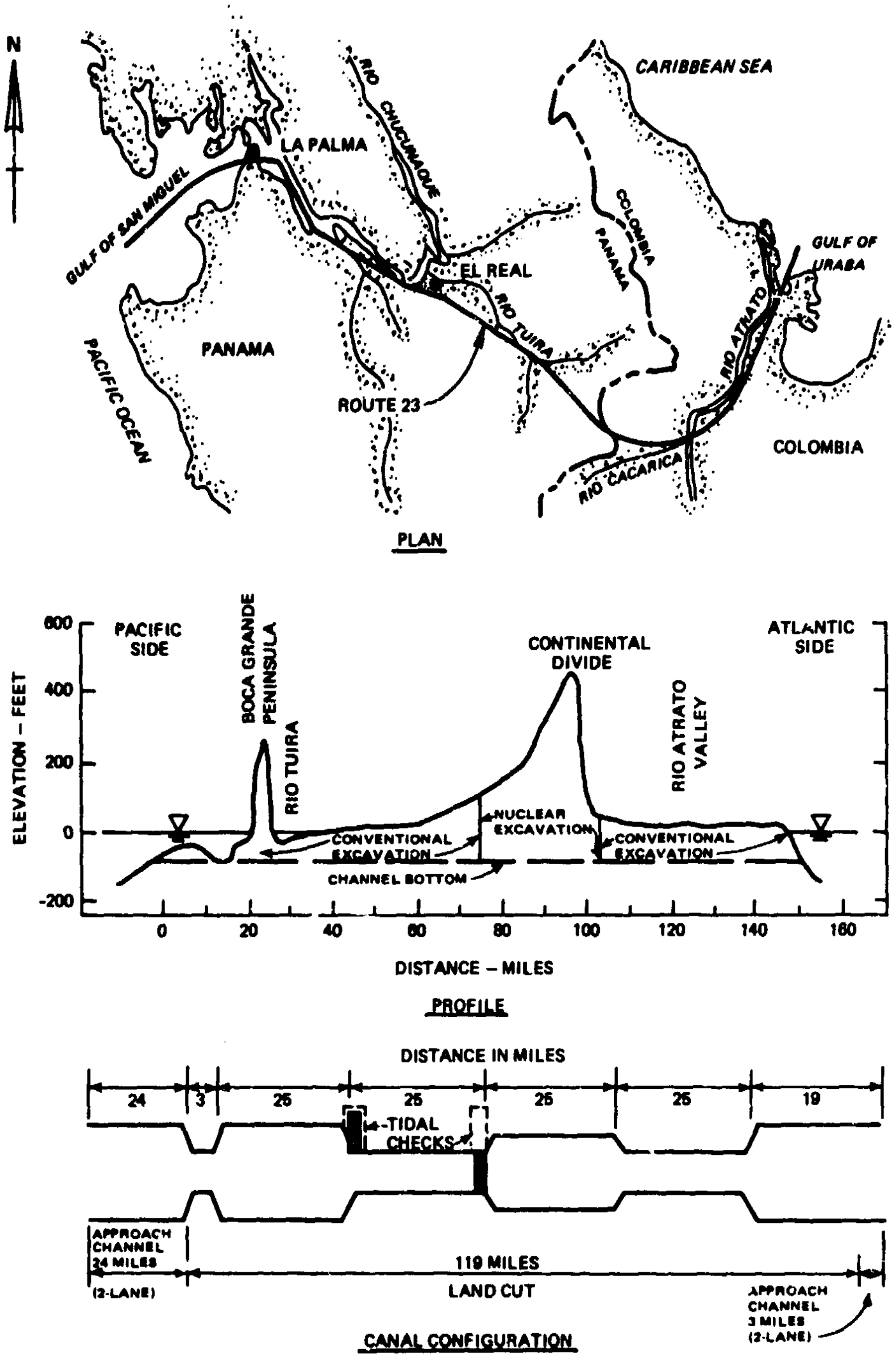
PANAMA-COLOMBIA BORDER AREA

SCALE IN MILES

5 0 5 10 15 20 25 30 35

DEPTHS IN FATHOMS

FIGURE 17-1



ROUTE 23
(WITH NUCLEAR DIVIDE CUT)

FIGURE 17-2

Construction: If nuclear excavation were used through the divide region, hydraulic dredging of the Tuira and Atrato reaches and river diversion channels would begin during the early phases of nuclear operations. Dredging operations within the exclusion area would be halted whenever required for radiological safety. Approximately 15 nuclear detonations averaging about 5 megatons each would be used, with the largest individual explosive yield being no more than 1 megaton. Throughout the 2-year nuclear operations period, detonations would be scheduled when atmospheric conditions would direct fallout toward the Pacific coast so that the exclusion area would not include La Palma. On completion of nuclear operations, full-time dredging would be resumed. At the same time, support facilities would be built and flood control structures completed. This partially nuclear excavated option is estimated to require at least 14 years to design and construct. The estimated cost is about $2.6 billion.

If conventional excavation were used for the divide cut, it would be by open-pit mining techniques. Except for the divide section, the entire canal would be excavated to 1,400-foot width to achieve desired transiting capacity. Fifteen years would be required to complete this canal and it would cost about $5.4 billion.

Either method of excavation would involve construction of extensive flood control works to divert or control the Atrato, Chucunaque, and Tuira Rivers. Other streams would be discharged into the canal by means of appropriate inlet structures. Tidal checks would be used to limit currents on both alternatives.

Problem areas: The most critical problem is the lack of reliable topographic and geologic data on which to base designs. Estimates for this route have assumed relatively competent rock, but it is possible that clay shales extend into the divide region where the deepest cuts would be required.* The presence of these shales in the divide might preclude nuclear excavation there. The presence of clay shales in the divide cut would cause a large increase in the excavation volume if conventional methods were employed.

The region is covered with jungle and is almost completely undeveloped. The local economy is insufficient to support the construction effort. Present port capabilities at La Palma and Turbo are limited to small craft, and more adequate port facilities would have to be built. Access to the area is limited to water routes which are good along the Atrato River and in the lower part of the Tuira River. There is no convenient access to the divide area and the supply of local labor is limited.

River diversion would be a major undertaking, particularly in the Atrato Valley. Seasonal floods of the Chucunaque, Tuira, and Atrato rivers, which carry heavy sediment loads, would necessitate control works to prevent shoaling of the channels.

If geologic conditions proved favorable, the low elevation of the divide in this area would permit construction of a wide channel with relatively small yield nuclear explosives, thus reducing the extent of the undesirable effects of nuclear excavation. However, construction of the divide cut by these techniques would require the evacuation of as many as 30,000 inhabitants from a land exclusion area estimated at 6,500 square miles. (See Figure 17-3). The exclusion area over the ocean would be operative only a short time, 1 to 2 days after each detonation.

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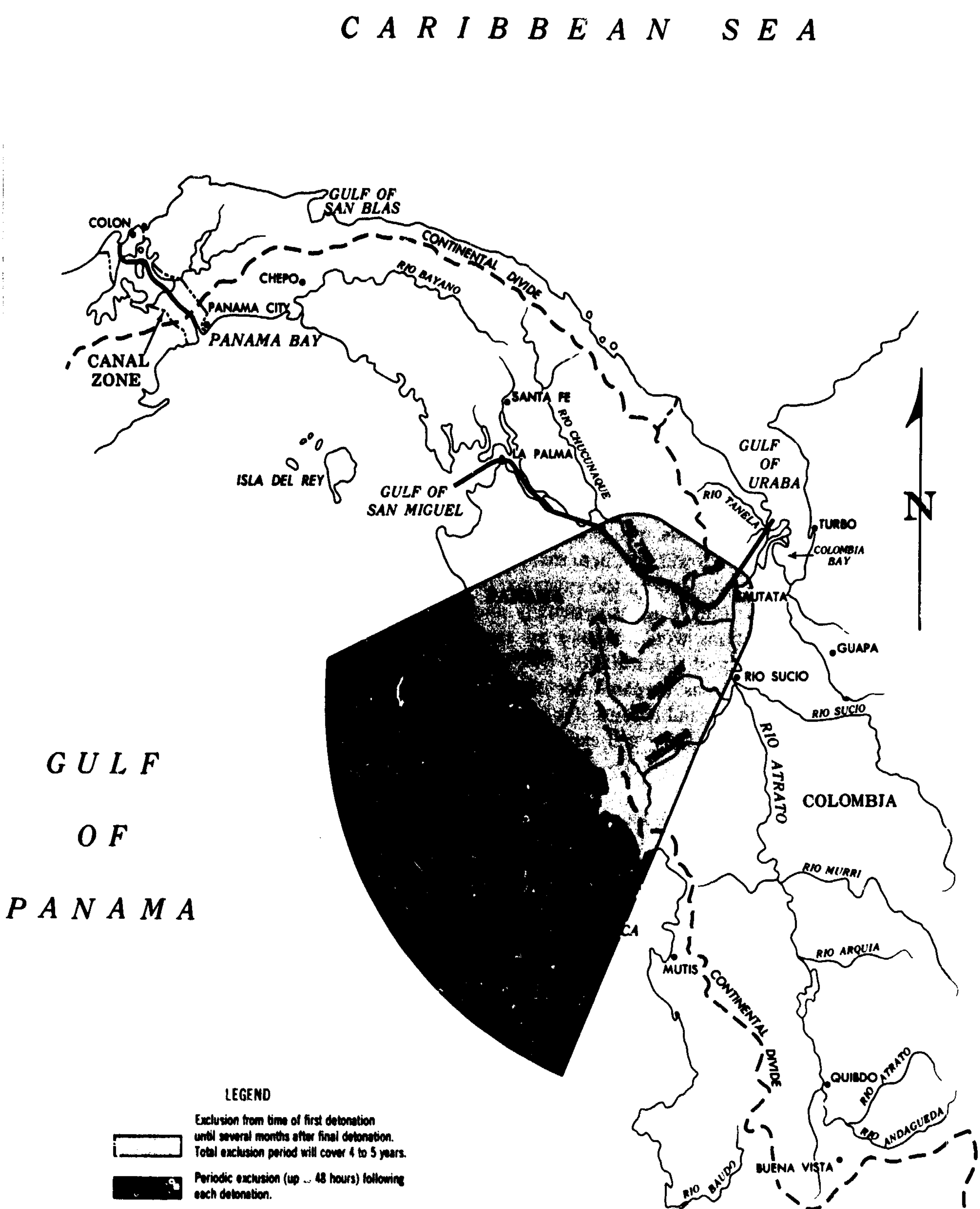
*Route 23 crosses the divide at a low point in an otherwise high range of hills which is structurally controlled. This low pass suggests that the material is weak and could be clay shale.



ROUTE 23 EXCLUSION AREA

SCALE IN MILES

25 0 25 50

FIGURE 17-3

Because this route crosses an international boundary, access to construction sites might be administratively complicated.

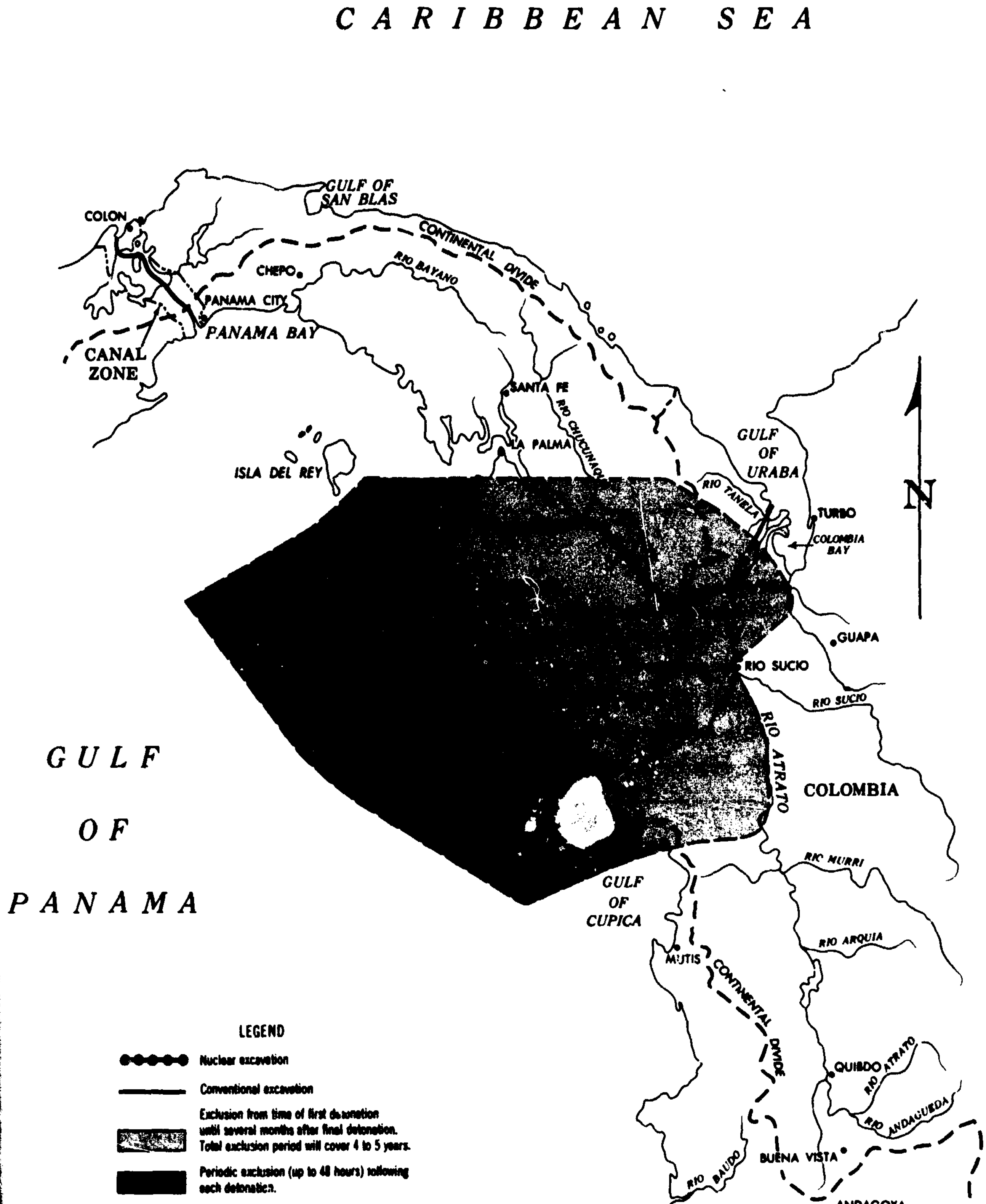
Alternate nuclear route: Late in the course of the study, an alternate alinement for Route 23 was suggested to allow greater use of nuclear explosives and possibly avoid slope stability problems in crossing the divide. This would be accomplished by starting the alinement in Garachine Bay on the Pacific, and running it almost due east, avoiding, insofar as possible, the low-lying Tuira Valley which does not appear suitable for nuclear excavation. This alinement would cross the divide north of the one previously discussed, meeting the Atrato River at Sautata, then turning northeast to Candelaria Bay. In the 20-mile reach between Sautata and Candelaria Bay, hydraulic dredging would be used; the rest of the land cut (84 miles) would be excavated by nuclear explosives. About 74 detonations would be required, with an average yield of 5.5 megatons. The largest detonation would be 7.5 megatons.

Assuming that nuclear explosives could be used as suggested, this alternative has certain advantages when compared with other routes constructed by nuclear means. Its low elevation would allow it to be excavated with a maximum single explosive yield of only 1.5 megatons. Construction costs would be comparable to those of Route 25, and a two-lane canal might be built at a lower cost here than on any other route.

These advantages depend on the existence of favorable geology over an 84-mile reach about which geologic knowledge is extremely limited. The canal would be about 120 miles long. Nuclear operations would require an exclusion area of about 8,000 square miles, containing a population of about 30,000. (See Figure 17-4).

No cost estimate was prepared for this alternative because it did not appear more favorable than Route 25, and because it was suggested after the Commission had determined that the feasibility of nuclear canal excavation could not be demonstrated within the next several years.

Summary data: The characteristics of Route 23 constructed by conventional means only are summarized in Table 17-1. Those of a canal employing nuclear excavation through the divide are in Table 17-2.



ALTERNATE NUCLEAR ROUTE 23
TENTATIVE TRACE AND EXCLUSION AREA

SCALE IN MILES

25 0 25 50

FIGURE 17-4

TABLE 17-1

CHARACTERISTICS OF ROUTE 23 CONVENTIONAL

Canal dimensions	550 x 75 ft (85 ft maximum depth)[a]
Length of land cut	119 miles
Length of approaches	27 miles
Design vessel[b]	150,000 dwt
Capacity[c]	50,000 transits/yr (20 hrs average TICW)
Construction time	15 years
Excavation volume	5,200,000,000 cu. yd.
Excavation cost	\$3,620,000,000
Other facilities	\$ 870,000,000
Contingencies	\$ 540,000,000
EDS&A[d]	\$ 360,000,000
TOTAL CONSTRUCTION COST	\$5,390,000,000
Operation and maintenance:	
Fixed costs	\$57,000,000/year
Variable costs	\$1,100/transit

[a]Based on a 25-mile long centrally located design channel through the divide, connected to the ocean by 2-lane channels, 1400 by 85 feet.

[b]250,000 dwt ships could transit in favorable currents.

[c]Based on continuous operation of tidal checks to limit current to a maximum of 2 knots.

[d]Engineering, design, supervision and administration.

	Favorable	Unfavorable
Supporting facilities		None exists capable of supporting construction and operation of an interoceanic canal.
Existing harbor facilities	Limited berthing for small craft exists at La Palma and Turbo.	None exists capable of handling deep draft vessels.
Harbor potential	Good on the Pacific side in the Darien Harbor area of the Gulf of San Miguel.	On the Atlantic side, harbor facilities must be constructed about 30 miles inland near Sautata where suitable foundations exist.

TABLE 17-1

CHARACTERISTICS OF ROUTE 23 CONVENTIONAL (Cont'd)

	Favorable	Unfavorable
Approaches/ coasts	Deep water is close in with fair protection on the Atlantic; the Pacific approach is well protected in the Gulf of San Miguel.	Intermittent sections of the 28-mile approach channel through the Gulf of San Miguel would need dredging.
Tidal currents		The location of the Pacific entrance of the canal in the wide Darien Harbor and estuary would make it difficult to hold currents to 2 knots or less.
Routes of communication		No roads or railroads exist in this part of Colombia and Panama. There are no all-weather airfields.
Terrain	The Atrato Valley is only a few feet above sea level. Maximum elevation is only about 450 feet.	Route is either dense forest or marshy terrain.
Geology	Limited investigations show much of the alinement is in alluvium or soft sediments.	Both surface and subsurface geology are poorly defined. There is a possibility that weak material requiring flat side slopes extends into the divide area.
Flood control and river diversion	Most of the river diversion can be accomplished with inexpensive hydraulic dredging.	Extensive flood control facilities would be required for the heavy seasonal flow of the Chucunaque, Tuira and Atrato Rivers. The Atrato River diversion is a major excavation in itself.
Construction features	Inexpensive hydraulic dredging could be used in the Atrato and Tuira River valleys.	Knowledge of physical characteristics of this route is extremely limited. Tidal checks would be massive engineering structures requiring special attention.

TABLE 17-1

CHARACTERISTICS OF ROUTE 23 CONVENTIONAL (Cont'd)

	Favorable	Unfavorable
Local development	Population density is under 5 persons per square mile. Inhabitants are engaged in fishing on the Pacific coast, slash- and-burn agriculture in the interior and lumbering along the Atrato River.	Lack of development would require all support for construction to come from outside of local area.
Environmental impact	Properly placed spoil should increase the land value.	The spoil disposal areas would be extensive.
Expansion possibilities		Significant expansion of capacity would require widening the divide cut.
Miscellaneous		Construction and operation might be complicated administratively because two host countries would be involved.

TABLE 17-2

CHARACTERISTICS OF ROUTE 23 NUCLEAR – CONVENTIONAL

Canal dimensions	See note a.
Length of land cut	119 miles
Length of approaches	27 miles
Design vessel[b]	150,000 dwt
Capacity[c]	50,000/yr (20 hrs average TICW)
Construction time	14 years
Conventional excavation volume	1,900,000,000 cu. yd.
Excavation cost	$1,170,000,000
Other facilities	$ 940,000,000
Contingencies	$ 290,000,000
EDS&A[d]	$ 170,000,000
TOTAL CONSTRUCTION COST	$2,570,000,000
Operation and maintenance:	
Fixed costs	$57,000,000/year
Variable costs	$1,100/transit

[a]Based on a 25-mile, 2-lane, 1,000-foot-wide nuclear section; a 53-mile design channel; and 68 miles of 1,400-foot-wide 2-lane channel including approaches.

[b]A 250,000 dwt ship could transit under carefully controlled conditions.

[c]Based on continuous operation of tidal checks to limit current to a maximum of 2 knots.

[d]Engineering, design, supervision and administration.

	Favorable	Unfavorable
Supporting facilities		None exists capable of supporting construction and operation of an interoceanic canal.
Existing harbor facilities	Limited berthing for small craft exists at La Palma and Turbo.	None exists capable of handling deep draft vessels.
Harbor potential	Good on the Pacific side in the Darien Harbor area of the Gulf of San Miguel.	On the Atlantic side, harbor facilities must be constructed about 30 miles inland near Sautata where suitable foundations exist.

TABLE 17-2

CHARACTERISTICS OF ROUTE 23 NUCLEAR – CONVENTIONAL (Cont'd)

	Favorable	Unfavorable
Approaches/ coasts	Deep water is close in with fair protection on the Atlantic; the Pacific approach is well protected in the Gulf of San Miguel.	Intermittent sections of the 28-mile approach channel through the Gulf of San Miguel would need dredging.
Tidal currents		The location of the Pacific entrance of the canal in the wide Darien Harbor and estuary would make it difficult to hold currents to 2 knots or less.
Routes of communication		No roads or railroads exist in this part of Colombia and Panama. There are no all-weather airfields.
Terrain	The Atrato Valley is only a few feet above sea level. Maximum elevation is only about 450 feet.	Route is either dense forest or marshy terrain.
Geology	Limited investigations show much of the alinement is in alluvium or soft sediments.	Both surface and subsurface geology are poorly defined. There is a possibility that weak material requiring flat side slopes extends into the divide area. This may preclude nuclear construction.
Flood control and river diversion	Most of the river diversion can be accomplished with inexpensive hydraulic dredging.	Extensive flood control facilities would be required for the heavy seasonal flow of the Chucunaque, Tuira and Atrato Rivers. The Atrato River diversion is a major excavation in itself.
Construction features	Inexpensive hydraulic dredging could be used in the Atrato and Tuira River valleys.	Knowledge of physical characteristics of this route is extremely limited. Tidal checks would be massive engineering structures requiring special attention.

TABLE 17-2

CHARACTERISTICS OF ROUTE 23 NUCLEAR – CONVENTIONAL (Cont'd)

	Favorable	Unfavorable
Local development	Population density is under 5 persons per square mile. Inhabitants are engaged in fishing on the Pacific coast, slash-and-burn agriculture in the interior and lumbering along the Atrato River.	Lack of development would require all support for construction to come from outside of local area.
Environmental impact	Properly placed spoil should increase the land value.	The spoil disposal areas would be extensive.
Nuclear effects	Air blast effects and potentially harmful fallout should be contained within the exclusion area. Risk of damage to metropolitan area is least of all nuclear routes.	
Exclusion area		Exclusion area is 90 miles wide and covers an area of about 6,500 square miles in which up to 30,000 people live.
Expansion possibilities	Widening through river valleys could be accomplished easily with minimum interference with operations.	
Miscellaneous		Construction and operation might be complicated administratively because two host countries would be involved.

CHAPTER 18

ROUTE 25 -- COLOMBIA SEA-LEVEL CANAL

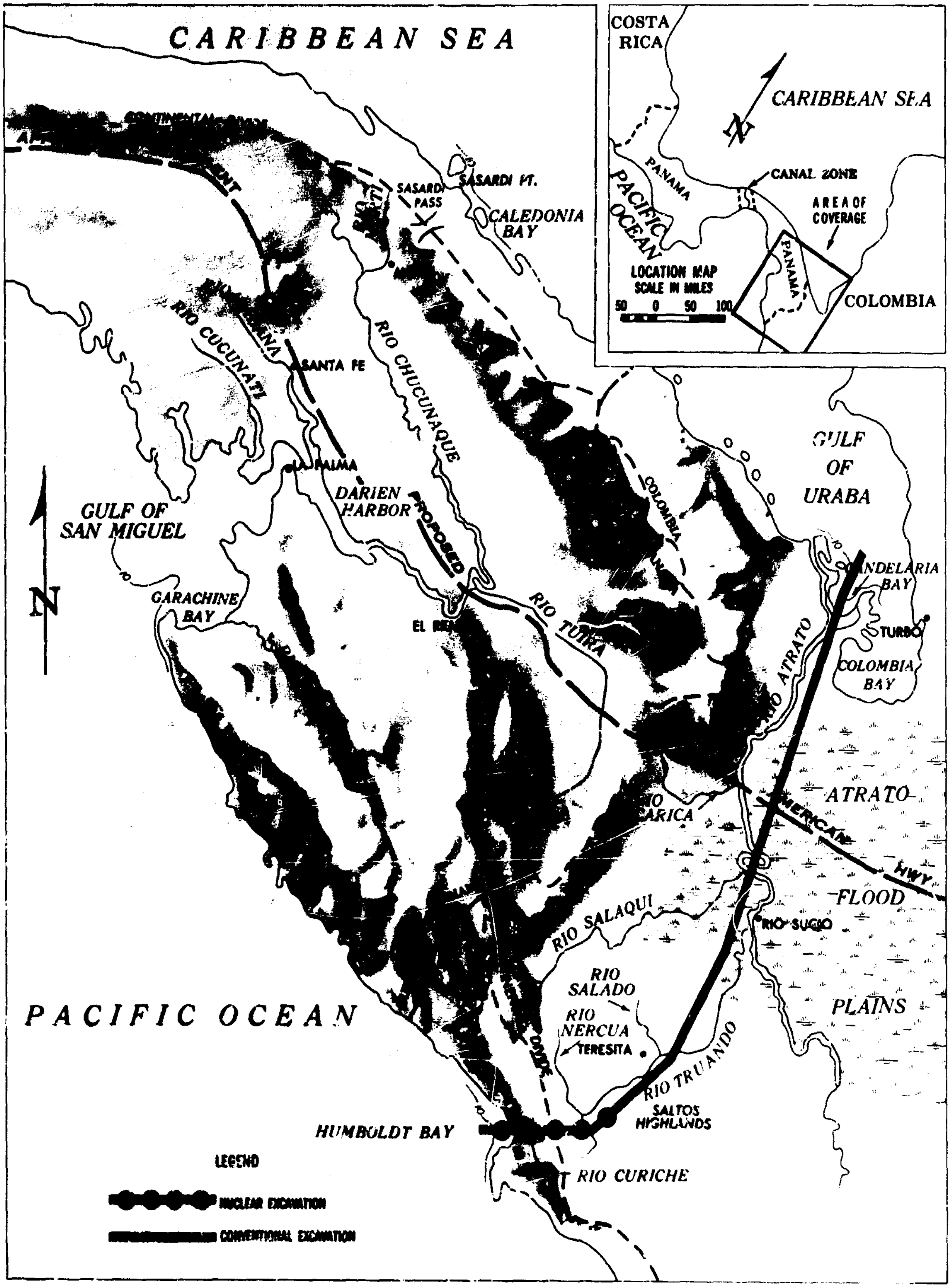
Route 25 was considered for construction by a combination of nuclear and conventional excavation methods, applied to take full advantage of the capabilities of each. Because of its remote location and the undeveloped character of the surrounding region, nuclear excavation techniques appear well suited for use on this route.

Accuracy of estimates: As was the case with Route 17, a data base has been developed which is adequate for evaluating this alternative with respect to other nuclear excavated routes.

Route 25 trace: (See Figure 18-1). Route 25 starts in Humboldt Bay on the Pacific Coast, approximately 200 miles southeast of Panama City. After crossing a narrow coastal strip, the alinement runs eastward for about 10 miles through the Choco Highlands which form the Continental Divide. Turning to the northeast, the trace crosses the upper Truando Valley and the Saltos Highlands and then parallels the Truando River to its confluence with the Atrato River. From there it passes through the Atrato Lowlands for about 50 miles, entering the Caribbean S[illegible] Candelaria Bay in the Gulf of Uraba at a point 2 miles from deep water. This alinement is 103 miles long, including 5 miles of approach channels; its peak elevation along the centerline is about 950 feet. Dense forests prevail except where the Atrato swamp does not support tree growth. Although the region is generally undeveloped, there are a few scattered settlements along the banks of the major rivers. The centerline profile of the route is shown in Figure 18-2.

Construction: The estimates for Route 25 assume the feasibility of nuclear excavation in a 20-mile reach from the Pacific coast through the Continental Divide, the upper Truando Valley, and the Saltos Highlands. Conventional excavation would begin at an elevation of about 300 feet in the Truando Valley, with shovel excavation and truck haul used at elevations above 75 feet. Over 90 percent of the conventional excavation would be at elevations lower than 75 feet and would be accomplished by hydraulic dredging.

Flood diversion measures would be extensive, since most of the Atrato River would have to be discharged into Colombia Bay through a 1,000- by 50-foot diversion channel east of the canal alinement. Bank revetment would be used to prevent meandering of the realined river and breaching of the separation between the diversion channel and the canal. A smaller but similar floodway west of the alinement would divert runoff from about 2,000 square miles of drainage area into Candelaria Bay. An inlet and several diversion channels,



ROUTE 25

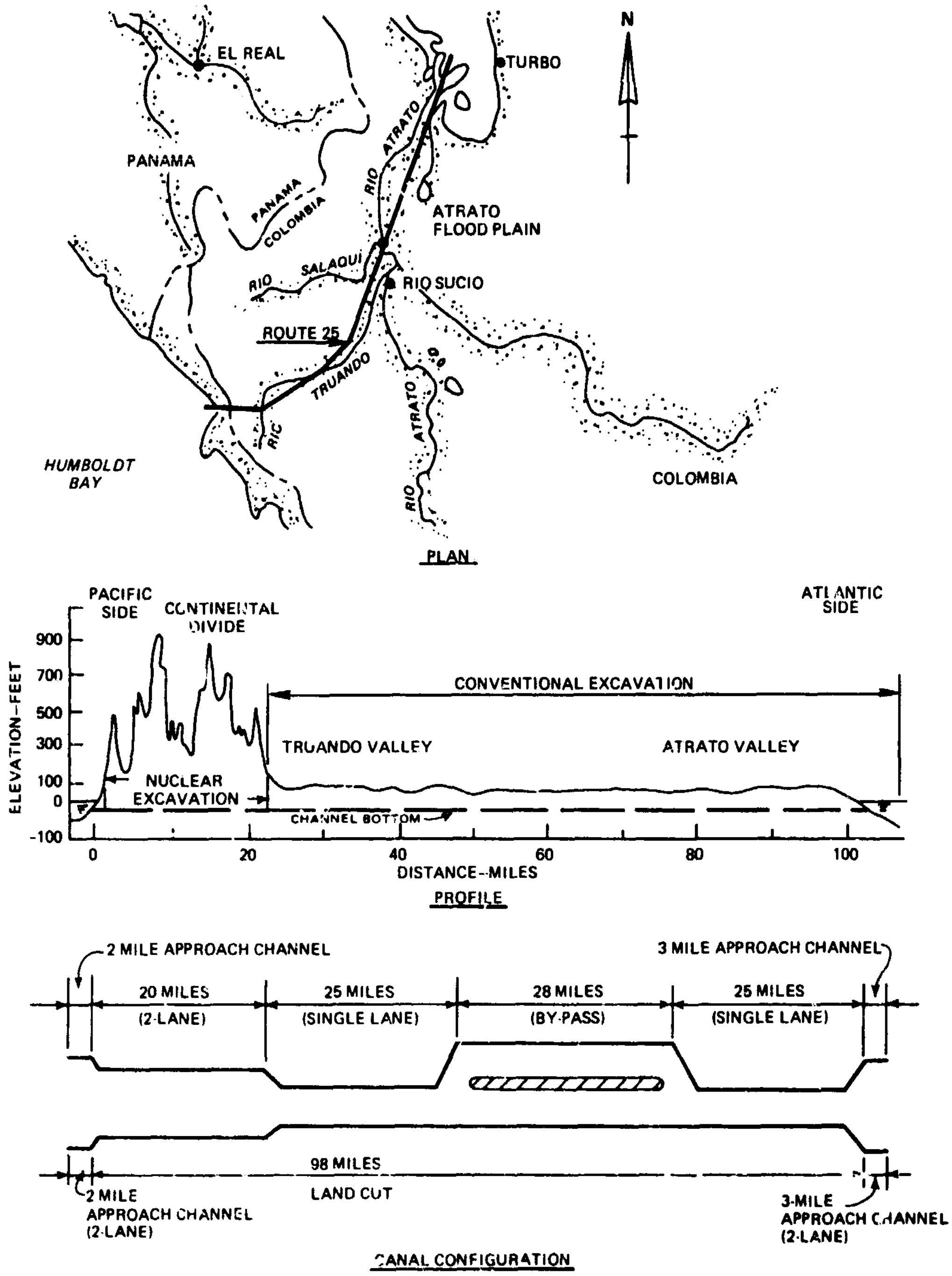
PANAMA-COLOMBIA BORDER AREA

SCALE IN MILES

5 0 5 10 15 20 25 30 35

DEPTHS IN FATHOMS

FIGURE 18-1



ROUTE 25

FIGURE 18-2

excavated with nuclear explosives, would be required to provide flood control and river diversion along the nuclear reach of the canal.

Hydraulic dredges would begin work on the canal within the Atrato flood plain early in the construction period. During nuclear operations, they would work at the north end of the alinement.

Nuclear excavation would require about 150 individual explosives detonated in 21 separate groups. Detonations would be scheduled in two passes, the first lasting 8 months and the second 6 months, with an interval of about 18 months to prepare for the second pass. The largest single detonation would be 13 megatons; the total yield of all explosives in the two passes would be about 120 megatons.

Because of the general lack of development in this region, all facilities required for constructing and operating the canal would have to be provided. These would include a transisthmian highway; harbor facilities; an all-weather airfield; administrative, maintenance, and residential facilities; lateral roads; and bridge or ferry crossings.

Construction of a sea-level canal on this alinement, with a 28-mile bypass channel, would cost approximately $2.1 billion; it would take about 13 years.

Problem areas: Without nuclear excavation, this route loses its advantages of low construction cost and inexpensive expansion potential. The land exclusion area (Figure 18-3) is about 3,100 square miles and has about 10,000 inhabitants. The exclusion area over the ocean would be operative only for a short time, 1 to 2 days after each detonation. Radiological surveys would have to be conducted continuously to determine when the area might be reoccupied. Some portions of the area could be re-entered shortly after the last detonation; however, it would probably be more practical to reoccupy the entire exclusion area, except for the immediate vicinity of the craters, at one time, 6 to 12 months after the last detonation. Some minor ground motion damage might occur in more distant population centers.

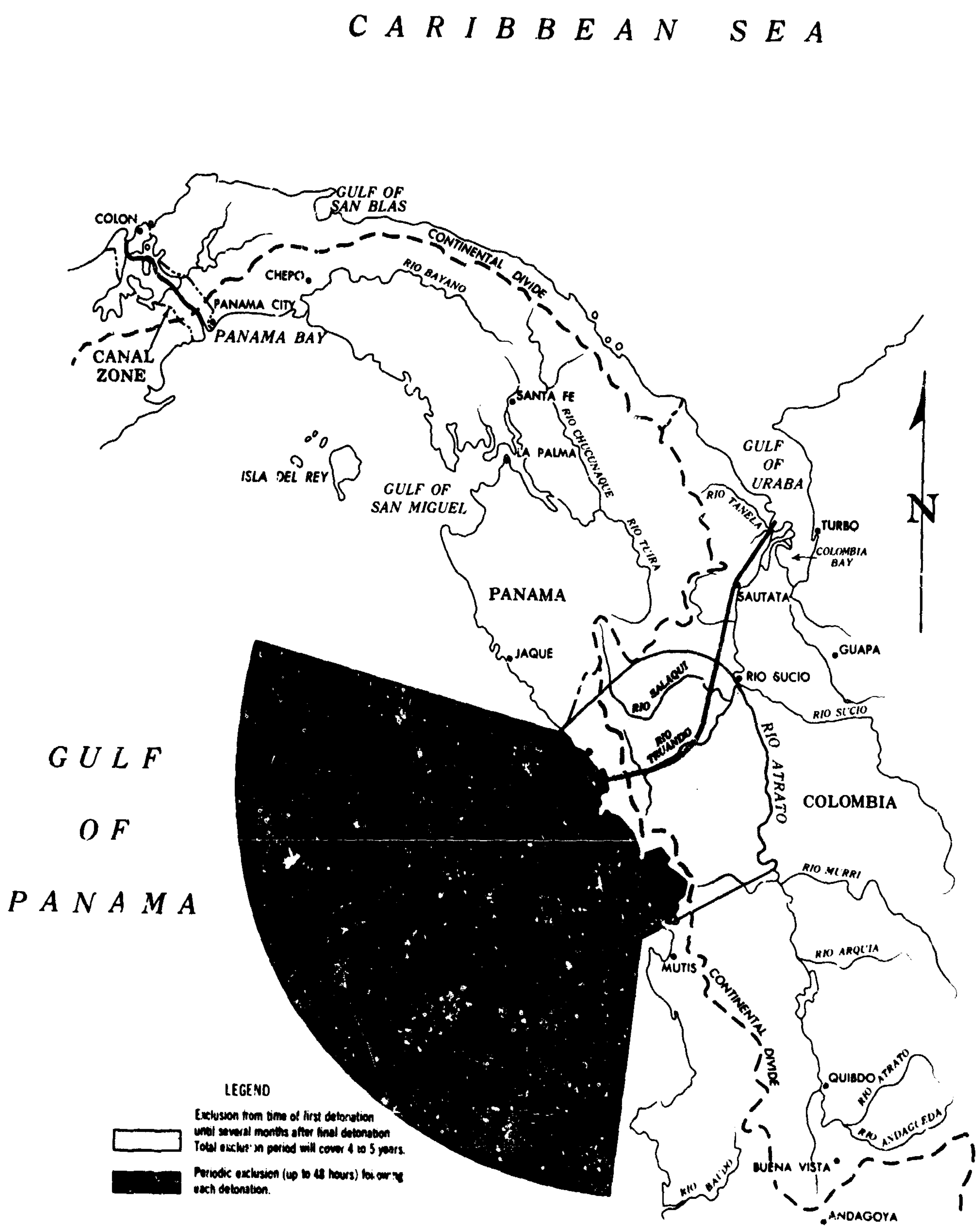
The length of Route 25 and the moderate range of Pacific tides in Humboldt Bay limit maximum tidal currents to 3 knots. To reduce these currents to 2 knots or less would require tidal checks. The one at the Pacific end of the canal would span a two-lane channel. This would be a very large gate with a high initial cost and a complex operating mechanism. These disadvantages appear to outweigh the advantages of insuring a slower current, which may eventually prove to be unnecessary. Therefore, tidal gates have not been included in the preferred design of this route, and operation with currents occasionally rising to 3 knots has been accepted. If necessary, traffic could be curtailed briefly in periods of highest currents without a significant reduction in the annual transiting capacity.

The local economy of the region is not sufficiently developed to support the construction operation. Most of the land in the Atrato Valley is marshy and unsuited for construction of facilities; the more solid ground is heavily forested. Adequate ports or anchorages would have to be built. At least one all-weather airfield would be needed and adequate land access into the area would have to be provided.

Subsurface geologic data collection on Route 25 was limited to 22 borings, most of which were concentrated in the divide area where material considered suitable for nuclear excavation was found. Only seven borings, supplemented by 27 soil probings, were made

across the lower Truando and Atrato valleys to determine the location of underlying bedrock.

Summary data: The characteristics)f Route 25 are summarized in Table 18-1.



ROUTE 25 NUCLEAR EXCLUSION AREA

SCALE IN MILES

25 0 25 50

FIGURE 18-3

TABLE 18-1

CHARACTERISTICS OF ROUTE 25

Canal dimensions	See note a.
Length of land cut	98 miles
Length of approaches	5 miles
Design vessel[b]	150,000 dwt
Capacity[c]	65,000 transits/yr (20 hours average TICW)
Construction time	13 years
Conventional excavation volume	1,700,000,000 cubic yards
Conventional excavation cost	$700,000,000
Nuclear excavation cost	$185,000,000
Other facilities	$850,000,000
Contingencies	$225,000,000
EDS&A[d]	$140,000,000
TOTAL CONSTRUCTION COST	$2,100,000,000
Operation and maintenance:	
Fixed costs	$49,000,000/year
Variable costs	$1,030/transit

[a]Based on a 20-mile, two-lane, 1,000-foot-wide nuclear section, a 78-mile conventionally excavated design channel with a 28-mile bypass section, and 5 miles of 1400- by 85-foot approach channels.

[b]A 250,000 dwt ship could transit in favorable currents.

[c]Based on a 3-knot maximum current. Capacity of other routes is based on a 2-knot maximum current.

[d]Engineering, design, supervision and administration.

	Favorable	Unfavorable
Supporting facilities		None exists capable of supporting construction and operation of an interoceanic canal.
Harbors	Limited berthing for small crafts exists at Turbo.	None exists capable of handling deep-draft vessels.
Harbor potential		Potential is poor on the Pacific side. On the Atlantic side harbor facilities must be constructed about 30 miles inland near Sautata where suitable foundations exist.

TABLE 18-1

CHARACTERISTICS OF ROUTE 25 (Cont'd)

	Favorable	Unfavorable
Approaches/ coasts	Deep water is close in on both coasts. Fair protection exists on the Atlantic.	No protection exists on the Pacific.
Tidal currents	Currents over 3 knots will occur on less than one day per month.	The canal's length and configuration make it difficult to provide tidal checks to hold currents to 2 knots or less.
Routes of communication	The Atrato River offers easy shallow draft passage to its confluence with the Truando River.	No transisthmian roads or coastwise roads exist in this part of Colombia. There are no railroads or all-weather airfields.
Terrain	Alluvial flood plain would allow inexpensive hydraulic dredging for most of the route and would permit easy expansion as needed.	Much of the route is through marshy terrain, complicating construction of facilities.
Geology	Borings in the divide reach indicate geologic conditions suitable for stable nuclear excavations. Bedrock in the Atrato delta appears to be well below desired channel depth.	Geologic data in the Atrato delta are limited.
Flood control and river diversion	Most of the extensive river diversion can be accomplished by hydraulic dredging.	The Atrato and the Salaqui Rivers carry large flows and silt loads which would have to be diverted away from the canal. Diversion of the Atrato River is a major excavation project.
Construction problems	This route presents no major slope stability problems; dredging operations would be routine.	Bank protection would be required to keep the meandering Atrato separate from the canal. The local labor supply is limited.

TABLE 18-1

CHARACTERISTICS OF ROUTE 25 (Cont'd)

	Favorable	Unfavorable
Environmental impact	Lack of local development would minimize the extent of the sociological impact of evacuation. Areas filled with spoil should become economically useful land in what is now an alluvial swamp.	The ecology of a large part of the lower Atrato swamp would be changed.
Nuclear effects	Most airblast effects and all potentially harmful fallout would be contained within the exclusion area.	Ground motion and airblast effects might cause some minor damage outside the exclusion area.
Exclusion area	The exclusion area would be the smallest of any of the nuclear routes.	The exclusion area would be about 3,100 square miles where it is estimated that 10,000 people now live.
Expansion possibilities	The nuclear excavated section would not require expansion. The long Atrato Valley reach is well suited for expansion in increments at relatively low cost.	
Local development	Population density is about 3 persons per square mile. Inhabitants are engaged in limited slash-and-burn agriculture, and in small-scale lumbering operations in the Truando Valley.	Lack of development requires all support for construction to come from outside the local area.
Miscellaneous	This is the least costly route for construction, provided nuclear excavation is feasible.	This is the longest shipping route from New York to San Francisco of the routes considered.

CHAPTER 19

SUMMARY OF ROUTE CHARACTERISTICS

This chapter consists of three summary tables which allow comparison of canal alternatives in three categories: conventionally excavated sea-level canals, sea-level canals excavated wholly or in part with nuclear explosives, and lock canals. The data shown are condensed from those given in the tables of characteristics which summarized the preceding discussions of the individual routes.

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TABLE 19-1

SUMMARY OF ROUTE CHARACTERISTICS — CONVENTIONALLY EXCAVATED

	8	10	14 Separate
Construction cost	$11,000,000,000	$2,880,000,000	$3,040,000,000
Operation and maintenance costs (35,000 transits/year)	$93,000,000/year	$56,000,000/year	$55,000,000/year
Initial capacity	35,000 transits/year	38,000 transits/year	39,000 transits/year
Design and construction time	18 years	14 years	16 years
Conventional excavation volume	7,000,000,000 cubic yards	1,870,000,000 cubic yards	1,950,000,000 cubic yard
Average time in canal waters	30 hours	20 hours	20 hours
Supporting facilities	Virtually non-existent. Granada can provide a limited support base.	Available in Canal Zone; ten miles from either terminus.	Virtually complete facilities at bal-Colon and Balboa-Panama Cit
Existing harbor facilities	Limited small boat facilities exist at San Juan del Sur.	Deep draft capability in Canal Zone. Needs expansion to hold large vessels. Shallow draft harbors on both coasts at Lagarto and Puerto Caimito.	Deep draft capability in Limon B Balboa. Needs expansion to ho vessels.
Harbor potential	Good on Pacific side in Salinas Bay. Poor on Atlantic.	Poor in immediate area; good in Canal Zone.	Fair on Pacific side; good on Atl Limon Bay.
Approaches and coasts	Unprotected on Atlantic side; Salinas Bay on Pacific. Deep water close in on both coasts.	Short approach with no protection on Atlantic side. Long approach with partial protection on Pacific.	Approaches are relatively long.
Tidal currents	Lowest current of all sea-level routes. Tidal gates not required.	Currents would exceed two knots. Continual use of tidal gates may be required.	Currents would exceed two kno tinuous use of tidal gates may quired.
Routes of communication	No transisthmian road or railroad. Coastal roads only on Pacific side. Waterborne transportation on San Juan River and Lake Nicaragua. No all-weather airfields.	No transisthmian facilities in immediate area. (See 14-S for facilities along lock canal.) Coastal roads on both sides. Route accessible from Gatun Lake.	With 14C, best of all routes. T all-weather transisthmian road. isthmian railroad. Coastwise ro all-weather airfields on both coas canal offers complete access.
Terrain (elevation shown is highest point along centerline)	Two mountain ranges separated by a marshy plain. Dense jungle predominates. Jungle alluvial coastal plain on Atlantic side. Maximum centerline elevation 750 feet.	Low mountain ranges near both coasts. Original jungle partially cleared. Arms of Gatun Lake cross route. Maximum centerline elevation 400 feet.	Essentially follows lock canal rou arate divide cut through unde land. Maximum centerline elevat feet.
Geology	Knowledge of subsurface geology limited. Surface data indicates geology conducive to canal construction. This is an area of active volcanoes.	Extremely variable. Subsurface geology data limited. Critical divide section may possibly require very flat side slopes.	Extremely variable. Well known formations in divide area would flat side slopes. Poor material an ations for flood control dikes i Lake.
Flood control and river diversion	Extensive flood control facilities are required for streams flowing into Lake Nicaragua and into the San Juan River.	Fewest flood control problems of all routes. Permanent barrier dams required on Gatun Lake arms.	Flood control dikes required ac tun Lake. Lowering of lake quired.
Local development	Basically undeveloped except on divide slopes where ranching predominates. Population density about 25/sq. mi. in this area; 5/sq. mi. throughout most of route where there are scattered patches of subsistence agriculture.	Area opening up to agricultural development. Dense jungle being cleared for cattle ranching. Subsistence farming giving way to truck farming. Population density varies from 5 to 25/sq. mi.	Region highly developed to interoceanic shipping.
Construction features	Level of Lake Nicaragua must be maintained.	No apparent problems except possible need for flatter slopes than now envisioned and barrier dam construction across arm of Gatun Lake. Good accessibility and supply of unskilled labor.	Gatun Lake would be maintai large flood control dikes. Flexib construction systems limited. Ca fic will be interfered with b endangered. With 14C, best acce and labor supply of all routes.
Environmental impact	Large area of San Carlos Plains would be cut off from access to Lake Nicaragua. Few inhabitants displaced.	Little harmful effect. A few small hamlets displaced.	Lake level drop and spoil dispos mental to Gatun Lake.
Expansion possibilities	Costly because of length.	Construction of a bypass would be fairly simple. Expansion to two lanes would require cuts through higher elevations than the original alinement.	Expansion to two lanes would deep cuts through areas of know bility.
Miscellaneous	Long land cut. Most angular sea-level route. This is a short New York-San Francisco sea-level route. Construction in two countries.	Offers easiest operation in conjunction with existing Panama Canal.	Construction of sea-level canal eli present lock canal as operable al route.

A

TABLE 19-1

CTERISTICS — CONVENTIONALLY EXCAVATED ALINEMENTS

	14 Separate	14 Combined	23
	$3,040,000,000 $55,000,000/year	$2,930,000,000 $55,000,000/year	$5,390,000,000 $95,000,000/year
r lc yards	39,000 transits/year 16 years 1,950,000,000 cubic yards 20 hours	39,000 transits/year 13 years 1,6[illegible],000,000 cubic yards 20 hours	50,000 transits/year 15 years 5,200,000,000 cubic yards 20 hours
ten miles from	Virtually complete facilities at Cristobal-Colon and Balboa-Panama City.	Virtually complete facilities at Cristobal-Colon and Balboa-Panama City.	La Palma and Turbo can provide a limited support base.
h Canal Zone. d large vessels. both coasts at to.	Deep draft capability in Limon Bay and Balboa. Needs expansion to hold large vessels.	Deep draft capabilities in Limon Bay and Balboa. Needs expansion to hold large vessels.	None capable of handling deep draft vessels. Shallow draft capability at La Palma and Turbo.
good in Canal	Fair on Pacific side; good on Atlantic in Limon Bay.	Fair on Pacific side; good on Atlantic in Limon Bay.	Good on Pacific side in Darien harbor; fair on Atlantic.
protection on ich with partial	Approaches are relatively long.	Approaches are relatively long.	Very well protected approach on Pacific side. Short partially protected approach on Atlantic.
wo knots. Con- ay be required.	Currents would exceed two knots. Continuous use of tidal gates may be required.	Currents would exceed two knots. Continuous use of tidal gates may be required.	Currents would exceed two knots in the Tuira estuary.
s in immediate ties along lock in both sides. un Lake.	With 14C, best of all routes. Two-lane all-weather transisthmian road. Transisthmian railroad. Coastwise road and all-weather airfields on both coasts. Lock canal offers complete access.	With 14S, best of all routes. Two-lane all-weather transisthmian road. Transisthmian railroad. Coastwise road and all-weather airfields on both coasts. Lock canal offers complete access.	No transisthmian or coastwise routes of communication except Atrato and Tuira Rivers. No all-weather airfields.
r both coasts. ated. Arms of Maximum cen-	Essentially follows lock canal route. Separate divide cut through undeveloped land. Maximum centerline elevation 450 feet.	Essentially follows lock canal route. Maximum centerline elevation 400 feet.	Two extensive alluvial valleys near sea-level separated by broad low mountain ridge. Heavily jungled where ground can support trees; otherwise marshy. Maximum centerline elevation 450 feet.
urface geology le section may ide slopes.	Extremely variable. Well known. Weak formations in divide area would require flat side slopes. Poor material and foundations for flood control dikes in Gatun Lake.	Extremely variable. Well known. Weak formations in divide area would require flat side slopes. Poor material and foundations for flood control dikes in Gatun Lake.	Both surface and subsurface geology virtually unknown. Possibility that weak Sabana shales extend into divide area.
oblems of all dams required	Flood control dikes required across Gatun Lake. Lowering of lake level required.	Flood control dikes required across Gatun Lake. Lowering of lake level required.	Extensive flood control facilities required for [illegible]o, Tuira and other streams.
tural develop- g cleared for ance farming g. Population /sq. mi.	Region highly developed to support interoceanic shipping.	Region highly developed to support interoceanic shipping.	Very little development. Minimum slash-and-burn agriculture. Fishing and limited ranching on Pacific coast. Population density 5/sq. mi.
xcept possible an now envis- construction Good accessi- ed labor.	Gatun Lake would be maintained by large flood control dikes. Flexibility of construction systems limited. Canal traffic will be interfered with but not endangered. With 14C, best accessibility and labor supply of all routes.	Gatun Lake must be maintained by large flood control dikes. Flexibility of construction systems limited. High risk of major interruption to lock canal operations exists in the divide cut due to slides of weak material. With 14S, best accessibility and labor supply of all routes.	No apparent problems but knowledge of physical characteristics of route is extremely limited. Accessibility and labor supply limited.
ew small ham-	Lake level drop and spoil disposal detrimental to Gatun Lake.	Lake level drop and spoil disposal deterimental to Gatun Lake.	The spoil area would be extensive. Properly placed, it could increase land value.
vould be fairly) lanes would her elevations	Expansion to two lanes would require deep cuts through areas of known instability.	Expansion to two lanes would require deep cuts through areas of known instability.	Generally unlimited. Much could be accomplished by hydraulic dredging.
n conjunction l	Construction of sea-level canal eliminates present lock canal as operable alternate route.	Construction of sea-level canal eliminates present lock canal as operable alternate route.	Construction in two countries.

B

TABLE 19-2

SUMMARY OF ROUTE CHARACTERISTICS, ALINEMENTS INCLUDING NUCLEAR

	8N	17	
Construction Cost	$5,170,000,000	$3,060,000,000	
Operation and maintenance costs (at 35,000 transits/year)	$88,000,000/year	$57,000,000/year	
Initial capacity[a]	200,000+ transits/year	42,000 transits/year	
Construction time	12 years	16 years	
Conventional excavation volume	50,000,000 cubic yards	1,600,000,000 cubic yards	
Average time in canal waters	20 hours	20 hours	
Supporting facilities	Virtually nonexistent. Granada can provide a limited support base.	La Palma can provide a limited support base.	La Palm base.
Existing harbor facilities	Limited small boat facilities exist at San Juan del Sur.	Limited on Atlantic side; shallow draft capability on Pacific at La Palma.	None Shallow
Harbor potential	Good on Pacific side in Salinas Bay; poor on Atlantic.	Good on both coasts for deep draft vessels after dredging.	Good Atlantic
Approaches and coasts	Unprotected on Atlantic side; Salinas Bay on Pacific. Deep water close in on both coasts.	Very long well protected approach on Pacific side. Short partially protected approach on Atlantic.	Very lo Short p
Tidal currents	Currents would reach two knots only occasionally. Lowest of all sea-level routes. Tidal gates not required.	Highest of all routes. Tidal checks would be in continuous use.	Current estuary.
Routes of communication	No transisthmian road or railroad. Coastal roads only on Pacific side. Waterborne transportation on San Juan River and Lake Nicaragua. No all-weather airfields.	No transisthmian or coastwise routes of communication. No all-weather airfields.	No tran cation weather
Terrain (elevation shown is highest point along centerline)	Two mountain ranges separated by a marshy plain. Dense jungle predominates. Jungled alluvial coastal plain on Atlantic side. Maximum elevation 1,000 feet.	Two mountain ranges separated by alluvial valley. Heavily jungled throughout. Maximum elevation 1,000 feet.	Low ex ted by where g Maximu
Geology	Knowledge of subsurface geology limited. Surface data indicates geology conducive to canal construction. This is an area of volcanic activity.	Subsurface investigations show twenty miles of weak clay shale which require flat side slopes and preclude use of nuclear explosives. Mountainous areas appear amenable to nuclear excavation.	Both s unknow which v use of n
Flood control and river diversion	Extensive flood control facilities are required for streams flowing into Lake Nicaragua and into the San Juan River.	Extensive flood control facilities required.	Extensi Atrato,
Local development	Basically undeveloped except on divide slopes where ranching predominates. Population density about 25/sq. mi. in this area; 5/sq. mi. throughout most of route where there are scattered patches of subsistence agriculture.	Very little development. Cuna Indian culture on Atlantic coast. Minimum slash-and-burn agriculture. Fishing and limited ranching on Pacific Coast. Population density 6/sq. mi.	Very lit agricult coast. P
Construction features	Loss of level of Lake Nicaragua possibly endangered by ground motion from nuclear detonations. Limited accessibility.	Conventional excavation cannot proceed until nuclear excavation completed. Side slopes in 20 miles of clay shales could present stability problems.	No appa characte cessibilit
Environmental impact	Large area cut off from access to Lake Nicaragua. Ejecta from detonations distributed all along route.	Strip along mountainous reaches would be covered with material ejected from craters. Extensive Indian culture uprooted.	Strips of with mat
Nuclear effects	San Jose and Managua would receive ground motion and airblast damage. Fallout hazards should be contained within exclusion area.	Possibility of some minor damage in Panama City from ground shock and airblast. Fallout hazards should be contained within exclusion area.	Risk of ground m
Exclusion area	Exclusion area is 150-200 miles wide, covers 21,000 square miles and includes 675,000 people.	Exclusion area is 100 miles wide, covers 6,500 square miles and includes 43,000 people. Best harbor site lies within exclusion area.	Exclusio miles and
Expansion possibilities	Expansion not considered necessary.	Generally unlimited. Twenty miles of conventional excavation would be required, almost all through clay shale.	Generall by hydra
Miscellaneous	With 8C, short New York-San Francisco route. Construction in two countries.		Construc

[a]At 20 hours time in canal waters.

A

TABLE 19-2

TERISTICS, ALINEMENTS INCLUDING NUCLEAR EXCAVATION

17	23 (Nuclear Divide Cut)	25
$3,060,000,000	$2,570,000,000	$2,100,000,000
$57,000,000/year 42,000 transits/year 16 years 1,600,000,000 cubic yards 20 hours	$95,000,000/year 50,000 transits/year 14 years 1,900,000,000 cubic yards 20 hours	$84,000,000/year 65,000 transits/year 13 years 1,700,000,000 cubic yards 20 hours
ma can provide a limited support base.	La Palma and Turbo can provide a limited support base.	Turbo can provide a limited support base.
l on Atlantic side; shallow draft capability fic at La Palma.	None capable of handling deep draft vessels. Shallow draft capability of La Palma and Turbo.	None on Pacific side. Shallow draft port at Turbo on the Atlantic side.
on both coasts for deep draft vessels after g.	Good on Pacific side in Darien harbor; fair on Atlantic.	Poor on Pacific side; fair on Atlantic in Candelaria Bay.
ng well protected approach on Pacific side. artially protected approach on Atlantic.	Very long well protected approach on Pacific side. Short partially protected approach on Atlantic.	Short approaches on both sides. Partial protection on Atlantic side; less on Pacific.
of all routes. Tidal checks would be in ous use.	Currents would exceed two knots in the Tuira estuary.	Currents over 3 knots will occur less than 1 day per month.
nsisthmian or coastwise routes of communi- No all-weather airfields.	No transisthmian or coastwise routes of communication except Atrato and Tuira Rivers. No all-weather airfields.	No transisthmian or coastwise routes of communication except Atrato River. No all-weather airfields.
ountain ranges separated by alluvial valley. jungled throughout. Maximum elevation eet.	Low extensive alluvial valleys near sea-level separated by broad low mountain ridge. Heavily jungled where ground can support trees; otherwise marshy. Maximum elevation 450-500 feet.	Extensive alluvial valley and single high mountain range. Heavily jungled where ground can support trees; otherwise marshy. Maximum elevation 950 feet
ace investigations show twenty miles of lay shale which require flat side slopes and e use of nuclear explosives. Mountainous pear amenable to nuclear excavation.	Both subsurface and surface geology virtually unknown. Possibility of weak clay shales in divide which would require rerouting or might preclude use of nuclear explosives.	Subsurface data indicates geology appears favorable for nuclear excavation in Continental Divide.
ve flood control facilities required.	Extensive flood control facilities required for Atrato, Turia, and other streams.	Extensive flood control facilities required for Atrato, Salaqui and other streams.
ttle development. Cuna Indian culture on c coast. Minimum slash-and-burn agricul- shing and limited ranching on Pacific Coast. ion density 6/sq. mi.	Very little development. Minimum slash-and-burn agriculture. Fishing and limited ranching on Pacific coast. Population density 5/sq. mi.	No development in divide region or Pacific coast. Lumbering in upper Atrato and Truando Valleys. Small town of Rio Sucio midway along route. Population density 3/sq. mi.
tional excavation cannot proceed until nu- cavation completed. Side slopes in 20 miles shales could present stability problems.	No apparent problems but knowledge of physical characteristics of route is extremely limited. Accessibility and labor supply limited.	None apparent. Accessibility and labor supply limited.
ong mountainous reaches would be covered material ejected from craters. Extensive ulture uprooted.	Strips of land along divide reach would be covered with material ejected from craters.	Strips of land along divide reach would be covered with material ejected from craters. A large expanse of the Atrato flood plain would be reclaimed.
ty of some minor damage in Panama City round shock and airblast. Fallout hazards be contained within exclusion area.	Risk of minor damage in metropolitan areas from ground motion is the least of nuclear routes.	Some minor damage may occur in distant population centers from ground motion effects. Fallout hazards should be contained within exclusion area.
n area is 100 miles wide, covers 6,500 miles and includes 43,000 people. Best ite lies within exclusion area.	Exclusion area 90 miles wide, covers 6,500 square miles and includes 30,000 people.	Exclusion area covers 3,100 square miles and includes 10,000 people.
y unlimited. Twenty miles of conventional on would be required, almost all through le.	Generally unlimited. Much could be accomplished by hydraulic dredging.	Easiest and cheapest of all routes to expand to the full two lanes. Can be accomplished almost entirely with hydraulic dredging.
	Construction in two countries.	Longest New York-San Francisco route.

B

TABLE 19-3

SUMMARY OF ROUTE CHARACTERISTICS, LOCK CANALS

	Route 5 Nicaragua
Design ship	150,000 dwt
Locks and size	double-lane, 3-lift; 1450 x 160 x 65 feet.
Channel size	500 x 65 feet (max 75 feet)
Summit pool elevation	105 - 110 feet
Channel bottom elevation	35 feet
Land cut	173 miles
Approach channels	4 miles
Capacity	25,000 transits/year (TICW 36 hours)
Construction cost	$5,700,000,000
Annual O&M cost	$110,000,000
Excavation volume	1,700,000,000 cubic yards
Construction time	12 years
Supporting facilities	Virtually nonexistent. Granada can provide a limited support base.
Existing harbor facilities	Limited small boat facilities exist at San Juan del Sur; even less at San Juan del Norte.
Harbor potential	Good potential exists at Salinas Bay, 35 miles southeast of Brito.
Approaches/coasts	Deep water close on both coasts. No protection except in Salinas Bay.
Routes of communication	No transisthmian road or railroad. Coastwise road only on Pacific side. Waterborne traffic on Lake Nicaragua; small boats on San Juan River. No nearby all-weather airfields.
Terrain	Jungle-covered, alluvial, coastal plain on Atlantic side. Low ranges of hills on both sides of Lake Nicaragua. Maximum cut at elevation 400 feet.
Geology	Surface data indicate geology is conducive to canal construction.
Flood control, river diversion and water supply	Adequate water supply available to meet transiting requirements. Large impoundment dam required.
Local development	Basically undeveloped except on divide slopes where ranching predominates. Population density 5/sq. mi. throughout most of route. Scattered patches of slash-and-burn subsistence agriculture in forests.
Construction problems	The locks and lock gates would be massive structures requiring special attention.
Environmental impact	Spoil disposal in Lake Nicaragua and oceans should present no problems. Population displacement would be minimal
Expansion possibilities	Costly because of length. Limited without construction of new locks.
Miscellaneous	Long land cut. Shortest New York-San Francisco lock canal route.

A

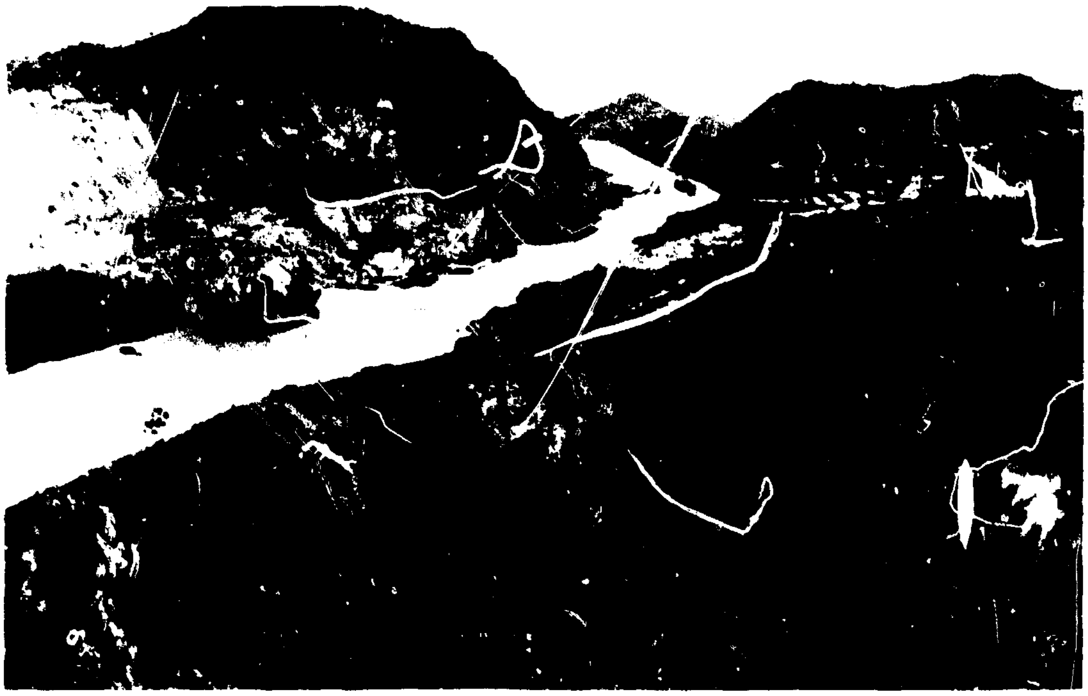
TABLE 19-3

OUTE CHARACTERISTICS, LOCK CANALS

5 Nicaragua	Route 15 Deep Draft Lock Canal
	150,000 dwt
et.	single-lane; 3-lift; 1,450 x 160 x 65 feet
	500 x 65 feet (max 75 feet)
	82 - 87 feet
	12 feet
	36 miles
	20 miles
	35,000 transits/year (TICW 25 hours)
	$1,530,000,000
	$71,000,000
	560,000,000 cubic yards
	10 years
ovide a limited support base.	Virtually complete facilities at Cristobal-Colon and Balboa-Panama City.
n Juan del Sur; even less at San Juan del	Deep draft capability in Limon Bay and at Balboa is not sufficient to accommodate 150,000 dwt ships.
5 miles southeast of Brito.	Fair on Pacific side; good on Atlantic in Limon Bay.
rotection except in Salinas Bay.	Approaches are relatively long.
stwise road only on Pacific side. Waterborne on San Juan River. No nearby all-weather	Best of all routes. Two-lane, all-weather, transisthmian road. Transisthmian railroad. Coastwise roads and all-weather airfields on both coasts. Water access available through existing canal.
on Atlantic side. Low ranges of hills on both t at elevation 400 feet.	Essentially follows present lock canal route and Third Locks cuts.
cive to canal construction.	Fairly well known; extremely variable. Weak formations in divide area would require flat side slopes.
et transiting requirements. Large	Must pump water to meet transiting requirements.
e slopes where ranching predominates. ut most of route. Scattered patches ve in forests.	Region highly developed to support Panama Canal shipping.
sive structures requiring special attention.	Mutual interference between canal traffic and construction effort can be expected.
ceans should present no problems. Popu- .	Pumping to augment water supply may render Gatun Lake brackish and increase interoceanic transfer of biota. Spoil disposal in Gatun Lake may disrupt ecology adversely.
out construction of new locks.	Limited without construction of new locks.
n Francisco lock canal route.	

B

The sailing ship "Lord Templeton" passing between Gold Hill and Contractor's Hill. June 12, 1915.



Culebra Cut looking south from the west bank near station 1760, showing condition of both banks. Feb. 25, 1915.

PART IV

COMPARISON OF THE MOST PROMISING ALTERNATIVES

From the foregoing analysis, it is apparent that:

– From a technical viewpoint, all of the sea-level routes which have been considered for construction exclusively by conventional means are feasible. Any of them could be constructed with techniques and resources now available. They are not, however, equally desirable. Some have characteristics which put them at a great disadvantage relative to other routes. (See Table 19-1.) Consequently, the routes listed below have been eliminated for further consideration in this study for the reasons shown:

Route 8 Conventional – Requires excessive excavation.
Route 14 Combined – Involves more interference with, and risk to, continuous operation of the Panama Canal during construction than does Route 14 Separate.
Route 23 Conventional – Requires excessive excavation.

– The feasibility of nuclear excavation techniques at suitably high explosive yields has not been established; hence, no route requiring nuclear explosives can be considered now as an alternative to a canal excavated by conventional means. It is possible, nevertheless, to discriminate among the several nuclear routes and to identify features which remove some of them from further consideration. (See Table 19-2.) These routes, with their principal disqualifying features, are:

Route 8 Nuclear – Displaces an unacceptably large portion of the populations of two countries.
Route 17 – Costs more than Route 25; the 20-mile reach across the Chucunaque Valley through clay shales requires costly conventional excavation, and presents continuing slope stability problems.
Route 23 Nuclear – There are insufficient data on which to make engineering estimates for either alternative involving nuclear excavation; longer and apparently more expense than Route 25.

– All lock canal options examined in this study are technically feasible; however, none could be expanded economically to meet the Commission's criteria for 60,000 annual transits by the year 2040. Between Route 5 and Route 15, Route 15 is clearly superior.

The most practicable conventionally excavated sea-level canal routes, together with the preferred nuclear route, will be examined in more detail in succeeding pages.* These routes and the principal reasons for their retention are:

Route 10	–	Involves relatively small excavation quantities; retains the full Panama Canal capability at minimum risk during construction and for as long as desired after construction; and has good supporting facilities available.
Route 14 Separate	–	Combines relatively small excavation quantities with the best available supporting facilities.
Route 25	–	Offers the least costly alinement for construction and subsequent expansion if the feasibility of nuclear excavation becomes established; retains the full Panama Canal capability.

*Even more detailed examinations appear in the appendixes: Route 10 and 14S in Appendix 10; Route 25 in Appendix 13.

CHAPTER 20

ROUTE 10

The alinement (Figure 14-1) and general characteristics of Route 10 have been described in Chapter 14.

Capacity: Three channel configurations proposed for Route 10 deserve serious consideration. Listed in increasing order of transit capacity* and construction cost, they are:

- A single-lane channel, 36 miles long;
- Two single-lane channels, each 11 miles long, connected by a 14-mile centrally-located two-lane bypass section; and,
- Two parallel single-lane channels, 25 miles long, with an extended Atlantic approach channel.

In each case the single-lane design channel would lie between 1,400- by 85-foot two-lane approaches. Each alternative would employ tidal check gates to limit currents. Figures 20-1a, -1b, and -1c show the locations of these gates and indicate how each alternative would be operated to hold tidal current velocities below 2 knots.

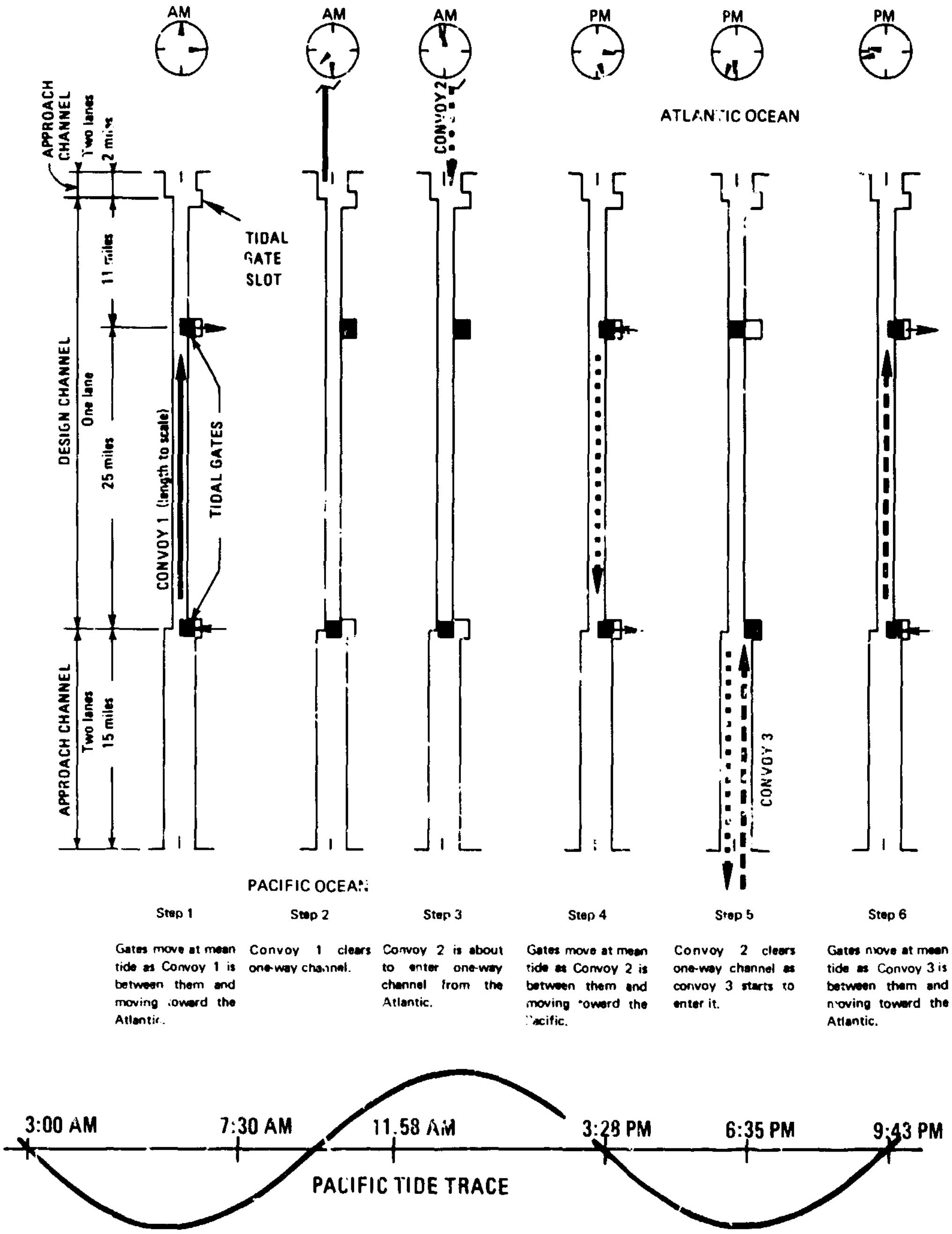
The single-lane channel would be built first. The bypass channel would be added to be available when traffic requirements exceed the capacity of the single-lane configuration†. The ultimate capacity would be reached by extending the bypass and the Atlantic approach channel to achieve a full two-way capability. Table 20-1 gives capacity-cost data for these configurations.

Channel design and ship spacing calculations were based on 150,000-dwt ships operating unassisted in 4-knot currents; however, because of lack of prototype experience, capacity calculations assumed a 2-knot maximum current limitation and the use of tugs to assist navigation. A tug fleet and tidal checks were included in cost estimates. Under these assumptions, with tidal checks in continuous use, the design channel would give slightly more than the desired initial design transit capacity. Table 20-2 summarizes the characteristics of the three Route 10 configurations.

In light of these considerations, the 36-mile single-lane channel was selected as the most appropriate for initial construction on Route 10. At first, currents in the canal would be kept under 2 knots by tidal checks located at the Pacific terminus and at a point 25 miles toward the Atlantic from the Pacific end. Capacities shown in this study are based on this

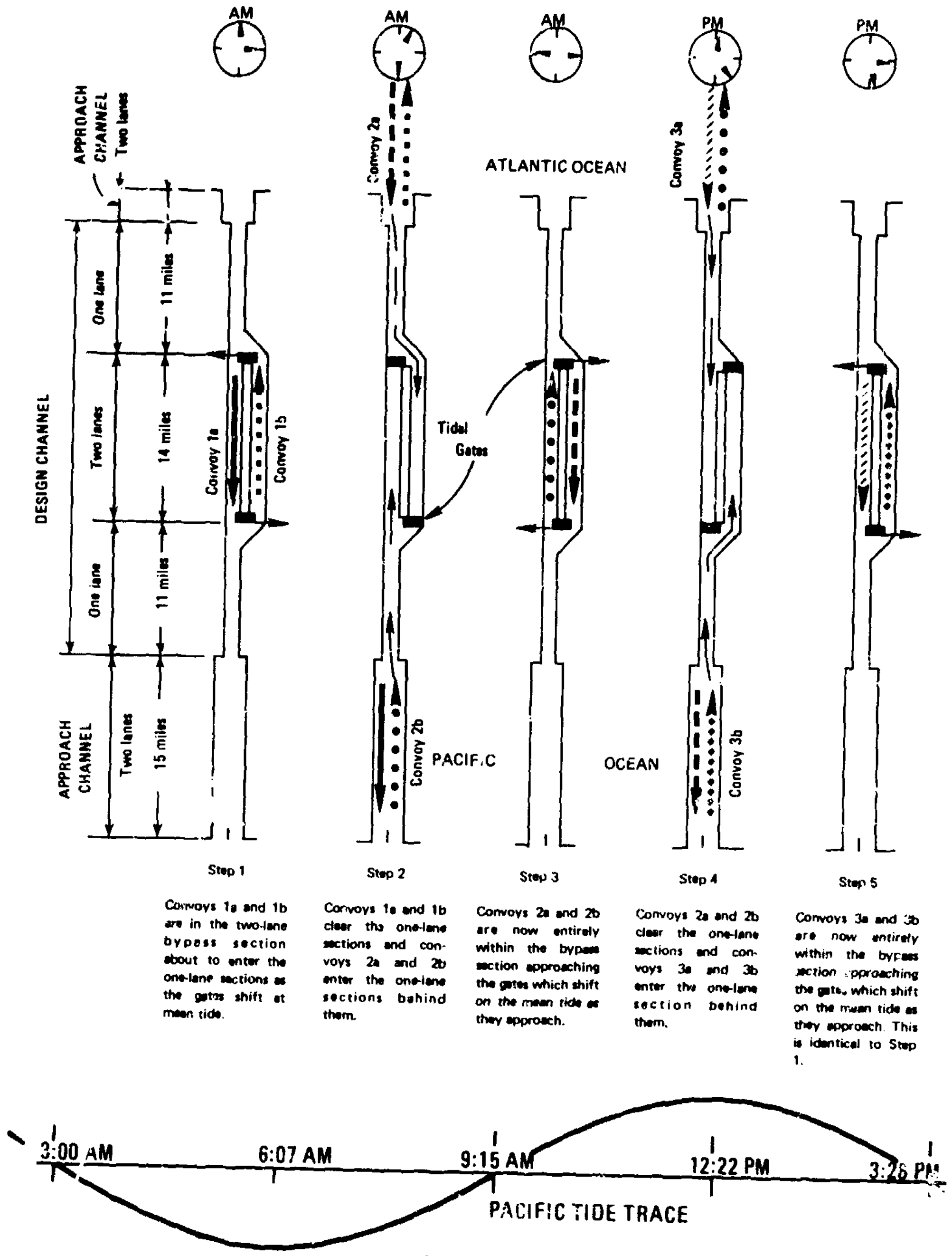
*For some limiting currents, the order of transiting capability would be different from that shown here. See Table 20-1.

†Construction of the bypass might be deferred until the demand for transits exceeds the capacity of a combination of Route 10 and the Panama Canal.



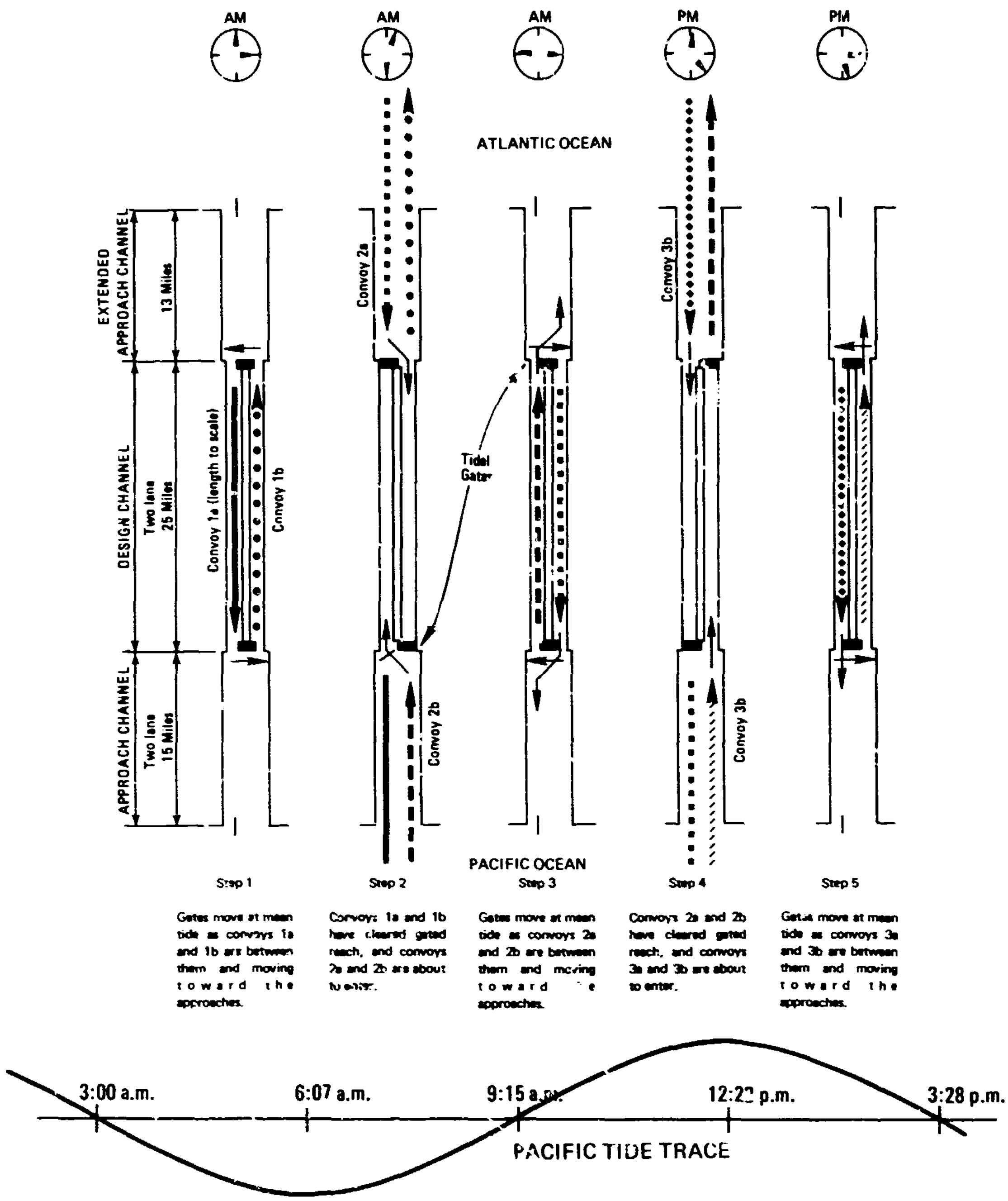
ROUTE 10
SINGLE-LANE
PLAN OF OPERATION
2-KNOT ALLOWABLE CURRENT
18.6-HOUR CYCLE

FIGURE 20-1a



ROUTE 10
BYPASS
PLAN OF OPERATION
2-KNOT ALLOWABLE CURRENT
6.2 HOUR CYCLE

FIGURE 20-1b



ROUTE 10
TWO-LANE
PLAN OF OPERATION
2-KNOT ALLOWABLE CURRENT
6.2-HOUR CYCLE

FIGURE 20-1c

TABLE 20-1

ROUTE 10 CAPACITY-COST DATA FOR DESIGN CHANNELS

Allowable Current and Configuration[a]	Annual Transits at 20 Hours Average TICW[b]	Average TICW[b] in hours at given Number of Transits per Year: 35,000	60,000	100,000
2 knots:				
Single	38,000	12	c	c
Bypass	56,000	6.2	c	c
Two-lane	114,000	5.5	5.5	5.9
3 knots:				
Single	45,000	14	c	c
Bypass	56,000	6.2	c	c
Two-lane	114,000	5.5	5.5	5.9
4 knots:				
Single	66,000	12	16	c
Bypass	57,000	6.3	37	c
Two-lane	195,000	5.0	5.0	5.0

Canal Configuration[a]	Estimated Incremental Construction Cost (W/Gates)[d]	Incremental Design and Construction Time[d]	Fixed O&M Cost /Year[e]
Single	$2,880,000,000	14 years	$35,000,000
Bypass	460,000,000	4 years	34,000,000[f]
Two-lane	1,520,000,000	7 years	41,000,000

[a]Single denotes a 36-mile single-lane channel; bypass denotes a 36-mile single-lane channel with a centrally located 14-mile-long bypass; and two-lane denotes a combination of two parallel single-lane channels and extended two-lane approach channels.

[b]TICW is time in canal waters, a combination of waiting time and transit time.

[c]Capacities cannot be achieved for the stated configuration or require a TICW of over 40 hours.

[d]Costs and time for the bypass configuration are the additional costs and time over and above those for the basic single-lane configuration; costs and time for the two-lane configuration are over and above those for the bypass configuration.

[e]Variable operation and maintenance costs would average about $640 per transit.

[f]The lower cycle times associated with the bypass configuration lead to more efficient use of operating personnel.

TABLE 20-2
CHARACTERISTICS OF ROUTE 10 CONFIGURATIONS[a]

	Single-lane Configuration	Bypass Configuration	Two-lane Configuration
Capacity	Would slightly exceed the initial transit requirement (35,000 transits per year) at 20 hours average TICW.	Would approach year 2040 transit requirement (60,000 transits per year).	Would exceed foreseeable requirement.
Average time in canal waters (TICW)	12 hours at 35,000 annual transits.	6.2 hours at 35,000 annual transits.	5.5 hours at 35,000 annual transits.
Navigation	Ship speed must be regulated to match tidal check operation.	Ship speed and spacing must be programmed carefully to fit the maximum number of ships into the bypass sections in each gate operation cycle. Unchecked currents would be higher than for other configurations.	Ship speed must be set to match tidal check operation. Configuration requires the most travel in a two-lane reach.
Flexibility of operation	Capacity, transit time, cycle time and TICW would be restricted by tidal check operation. Flexibility would improve with higher acceptable currents.	Convoy size would be limited as long as the bypass is used, but the canal may be used in a single-lane configuration. Capacity, transit time, cycle time and TICW would be restricted by tidal check operation	Great flexibility would exist despite the need to use tidal gates.
Expansion	Could be expanded to bypass configuration without serious interference with traffic.	Could be expanded to two-lane configuration without serious interference with traffic.	No foreseeable need
Capacity at higher limiting current	Would exceed year 2040 transit requirement at 4 knots.	Relaxing the current limitation would not increase transit capacity.	Would exceed any foreseeable requirement at 2 knots or above.

[a]Based on the design channel and, except where specifically stated, a maximum current of 2 knots. Tidal check gates would be in continuous use.

method of operation. To allow for the possibility that these current limitations might be unduly restrictive, a third gate sill would be constructed at the Atlantic end to facilitate subsequent installation of another tidal check that could be used in conjunction with the check on the Pacific side to permit maximum current velocities to reach 3 or 4 knots, thereby increasing the canal's capacity.

Geology: The alinement passes through two markedly different geologic regions. The area from the Pacific shore to the southern portion of the Chagres basin is an igneous complex composed of basalt flows intercalated with highly altered tuffs and agglomerates. This area, which includes the Continental Divide, contains local basalt intrusives and

extrusives and is bordered by thick deposits of muck in the littoral swamps and lowlands. Excavation of the northernmost 10 miles of the alinement, lying between Gatun Lake and the Atlantic coast, would encounter only sandstone formations. In Gatun Lake and along the coastlines these sedimentary rocks are mantled by thick deposits of muck.

The geologic characteristics of the divide are significant, since about 60 percent of the total excavated volume would be from this sector. To enhance the reliability of Route 10 cost estimates, the Commission undertook a geologic exploration program, concentrated primarily in this reach. The geology of the divide area, shown in profile in Figure 20-2, is extremely complex structurally. It is the result of intermittent volcanic activity and a series of north-south normal faults controlled by regional tectonic forces.

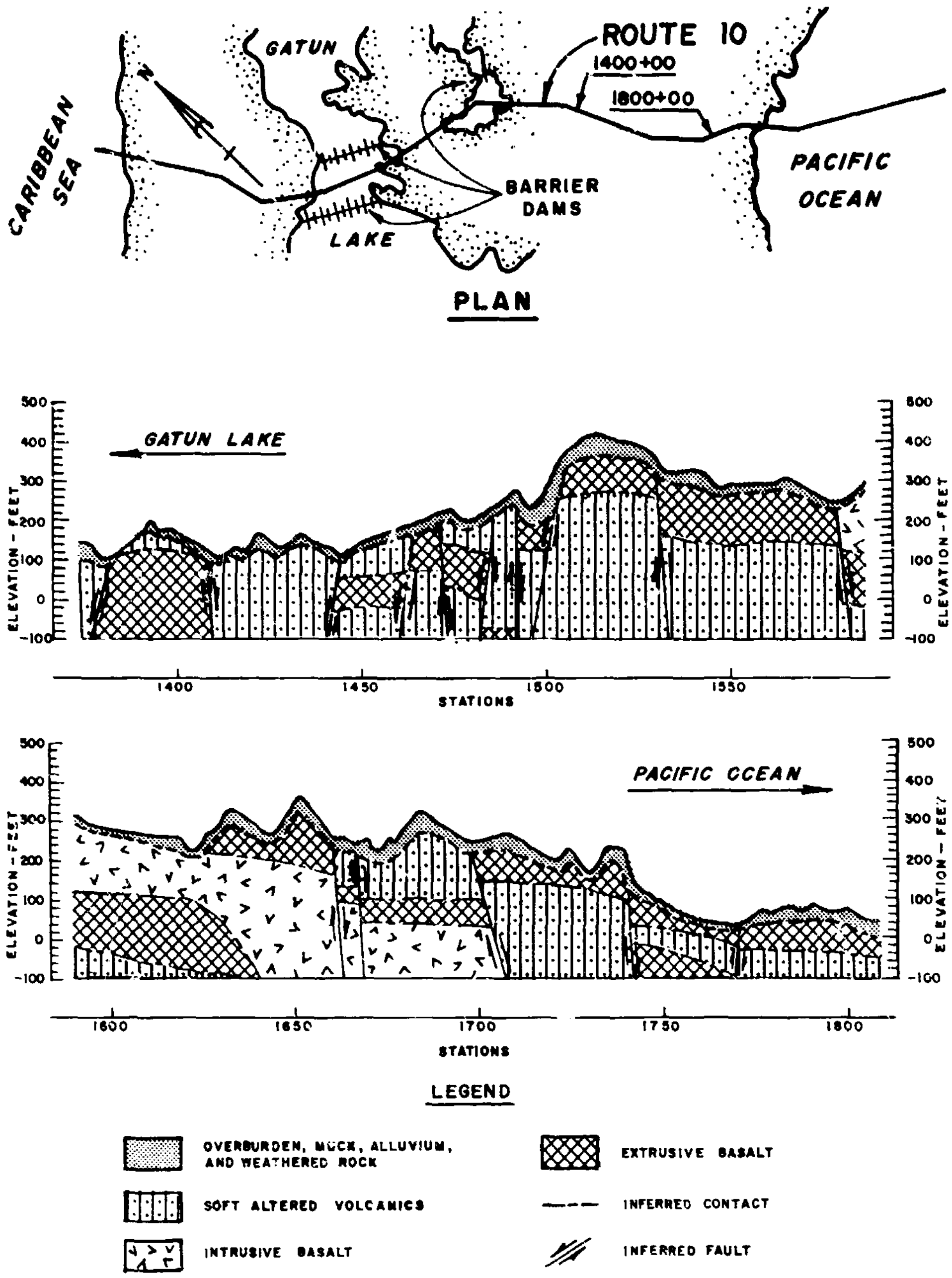
Geologic samples taken during the exploration show wide variations in strength, indicating that channel side slopes required for stability within the divide reach would also vary through a wide range. Where sound rock extends well below channel depth, excavation could be based on slope criteria established for high quality rock. In other areas, including the highest portions of the divide, the massive basalt cap and underlying basalt flows do not extend to the bottom of the cut. The basalt is underlain by or intercalated with softer rocks, including altered volcanics which exhibit the weakness and general characteristics of clay shale. Where these weaker rocks would be exposed by excavation, slope design would have to be based on criteria established for soft rock.

The remainder of the land cut from the foothills of the divide northwest across Gatun Lake into the Atlantic would be through sedimentary rock of the Chagres, Gatun, and Caimito formations. Elevations in this area reach a maximum of 360 feet. Design of the slopes in these sandstone formations could be based upon criteria for intermediate quality rock. As evidenced by the Third Locks cut, made through the Gatun formation during 1939-1942, these rocks would stand on relatively steep slopes. The Chagres and Caimito formations were not exposed in the Third Locks excavation but they closely resemble the Gatun formation geologically and could be excavated on similar slopes.

The Atlantic approach consists largely of Chagres sandstone; the reach across Gatun Lake consists of Caimito and Gatun sandstone covered by thick deposits of muck; and the Pacific approach consists of intrusive basalt and soft altered volcanic rocks. Cuts in these sections would be relatively shallow.

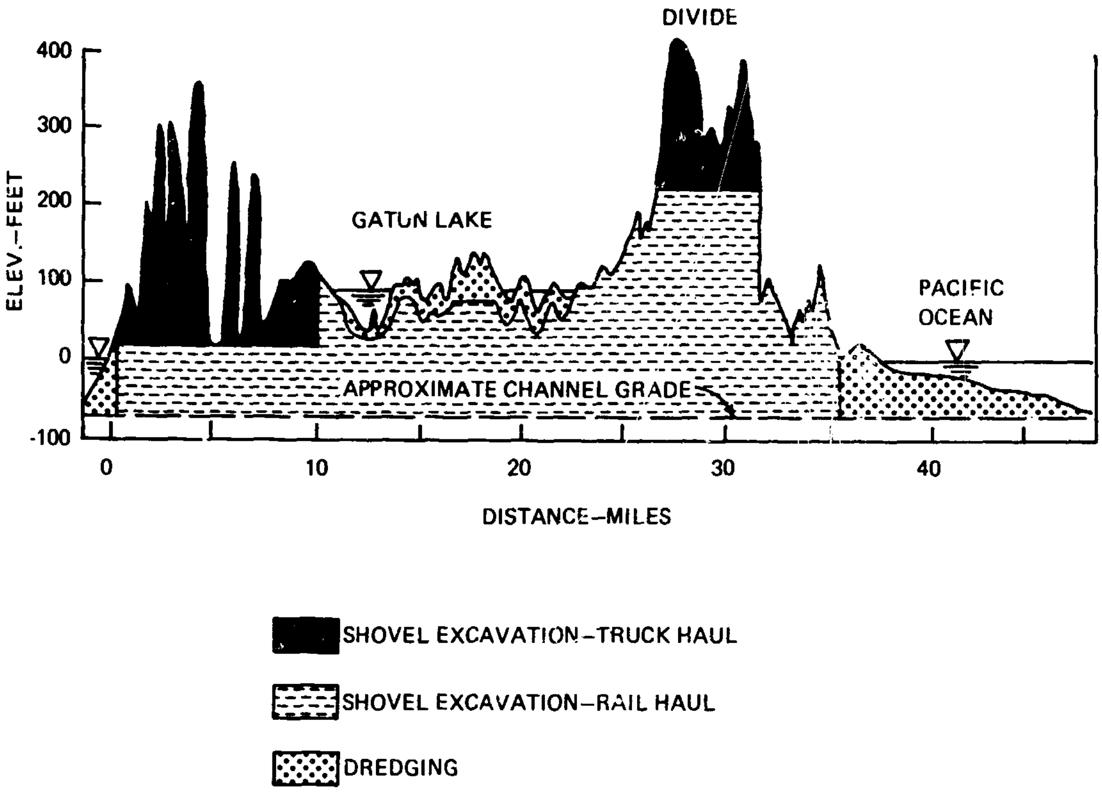
Excavation: The total quantity of material excavated along Route 10 would be about 1.9 billion cubic yards. An open-pit mining/rail haul system would be the least costly method for accomplishing most of this work. Shovel excavation with truck haul could be used in the higher elevations. The general excavation plan upon which estimates were based is shown in Figure 20-3.

Apart from the unprecedented amount of material to be removed, the only unusual feature of Route 10 excavation operations would be the construction of massive barrier dams built across relatively narrow reaches of Gatun Lake. These would allow work areas to be unwatered to permit excavation in the dry over most of the route. The cross section of the dams is shown in Figure 20-4 along with their location. Initially, hydraulic pipeline dredges with 27-inch discharge lines would remove as much as 50 feet of muck from the lake bottom under the dam sites to expose competent rock. Fill would then be placed by trucks and rail cars working out into the lake from the shorelines and dumping along a



GEOLOGIC PROFILE
CONTINENTAL DIVIDE
ROUTE 10

FIGURE 20-2



Generalized Excavation Methods
Route 10

FIGURE 20-3

2,000-foot advancing face. Although there is no precedent for constructing a dam of this size in this manner, it appears entirely practicable for this project. There is ample precedent for excavation and fill placement in water depths comparable to those in Gatun Lake.

Areas which could not be excavated economically in the dry would be excavated with floating equipment. Hydraulic pipeline dredges would remove muck and soft rock in the Atlantic approach and across Gatun Lake. Hopper dredges would be used for the soft materials in the Pacific approach, while barge-mounted draglines would excavate the harder materials.

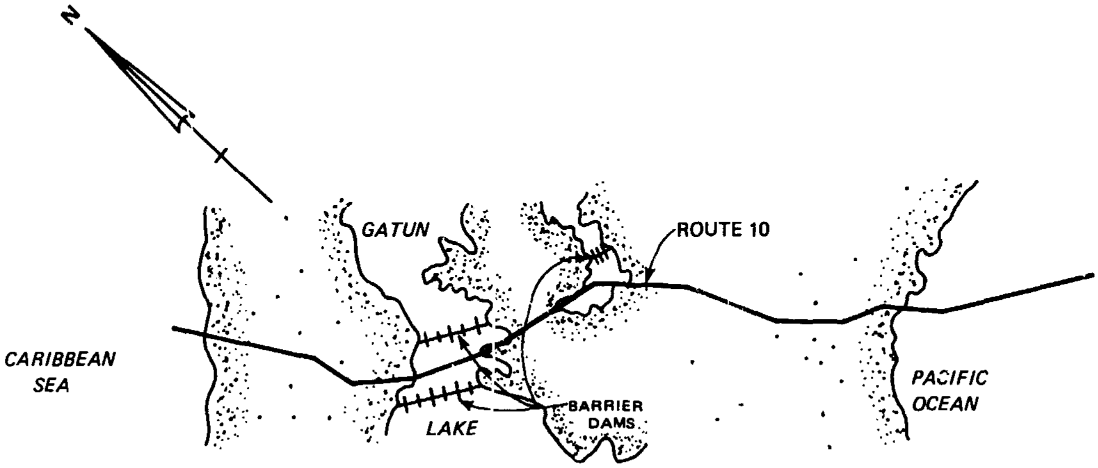
Excavation alone would cost about $2.0 billion, including $50 million for barrier dam construction. Quantities of materials removed, by type, would be:

Type of material	Cubic yards	Percent
Common	390,000,000	21
Soft rock	830,000,000	44
Medium rock	180,000,000	10
Hard rock	470,000,000	25
Total	1,870,000,000	100

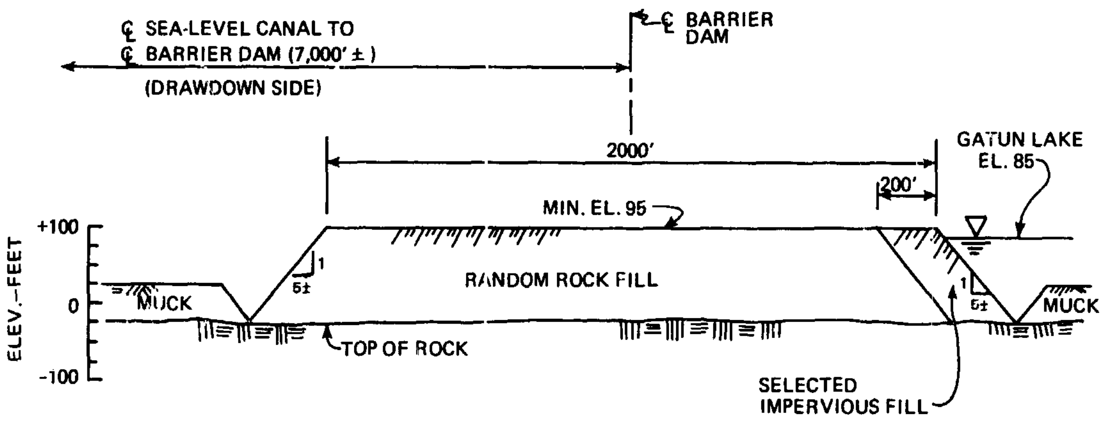
Spoil disposal areas: Adequate spoil disposal areas would be available because of the undeveloped nature of most of the land around Route 10 and the accessibility of Gatun Lake and the ocean areas immediately adjacent to the canal's terminals. Most of the material would be removed by open-pit mining/rail haul operations and would be deposited on land presently covered by jungle growth. This would involve the least total cost and would minimize dumping in Gatun Lake, where ecological values might be affected, and in the ocean, where operations could be hindered by rough water and shallow depths.

Stream diversion: Streams affected by construction of the canal along Route 10 would include the Trinidad and Ciri Rivers (drainage areas totalling about 288 square miles) and Caño Quebrado (drainage area about 70 square miles). They would be canalized and diverted to the Caribbean by way of the Lagarto River at whose mouth a dam and a short diversion channel would turn the discharge of the streams away from the canal's terminus. The Caimito River (drainage area about 127 square miles) would discharge over a spillway directly into the canal. Concrete weirs and drop inlet structures would be constructed wherever major changes in natural stream slopes occur. Flood diversion plans are shown on Figure 20-5. The total cost of flood control and diversion facilities is estimated to be approximately $20 million.

Harbor facilities: Requirements for new port facilities would not be extensive, since those now existing at Cristobal and Limon Bay on the Atlantic coast and at Panama and Balboa Harbor on the Pacific could be adapted to serve Route 10. These facilities would require enlargement as traffic increases. Portions of the channels and harbor areas would have to be deepened to accommodate larger vessels, but it would not be necessary to provide docks for ships of more than 40-foot draft, since protected mooring areas would



PLAN



BARRIER DAM CROSS-SECTION

ROUTE 10 – BARRIER DAMS

FIGURE 20-4

suffice. Wharves and miscellaneous administrative and storage buildings would be built at the canal terminals. The general location of harbor facilities is shown on Figure 20-5; their cost would be about $37 million.

Also shown in Figure 20-5 are locations of breakwaters on the Atlantic side and of a jetty on the Pacific. These structures would be built with rock excavated from the canal. The breakwaters would shelter the harbor from northeasterly storms, while the jetty would protect the approach channel from westward littoral drift.

Tidal checks: The costs of constructing and operating tidal checks are included in all estimates. Several types of gates have been proposed; these are shown and discussed in Chapter 8. In addition to fabricating the gates, construction of tidal checks would entail placing the sills, providing side wall recesses into which the gates would fit when open, and installing control mechanisms. The cost of the tidal checks, estimated to be about $70 million, includes all below-water construction required for alternate current limitation options.

Conversion: The construction of barrier dams to isolate Route 10 from Gatun Lake would allow operation of the sea-level canal without physically affecting the Panama Canal. No special construction would be required to convert operations from the lock canal to Route 10.

Supporting construction: A number of items would be required to support the construction operations. These include health and sanitation facilities, housing, highways and bridges, clearing and relocations, and the installations needed for operating and maintaining the canal. The total cost of these items would be about $247 million.

- **Health and sanitation:** Experience with large construction projects in the tropics emphasizes the need for a vigorous preventive medicine program with stringent sanitary measures. This program must begin during preconstruction planning, continue throughout the entire construction period and carry on into the operational phase. Particular attention should be given to immunization, water and sewage treatment, food service sanitation, insect and rodent control, water drainage, area sanitation, waste disposal, and health education. Immunization would be directed primarily against yellow fever, smallpox, typhoid fever, poliomyelitis, and tetanus. Malaria prevention would have a high priority.

  An extensive medical support plan would be instituted at the start of the project and phased into post-construction operations. Hospital support would be based at existing facilities in the Canal Zone where an estimated additional 50 beds would be needed for the construction force, including dependents. A dispensary would be established at each end of the route to provide medical service to its area; first aid stations would be set up at the major construction sites. The dispensaries would continue in operation at reduced levels after the completion of construction.

  Medical support would be designed especially to care for construction accidents and to alleviate the effects of malaria and other parasitic diseases, enteric infections, skin diseases, and other tropical ailments. Both medical support and preventive medicine programs would have to be coordinated closely with Canal

ROUTE 10 FLOOD CONTROL AND SUPPORT FACILITIES

THE CANAL ZONE AND VICINITY

FIGURE 20-5

SCALE IN MILES
5 0 5 10

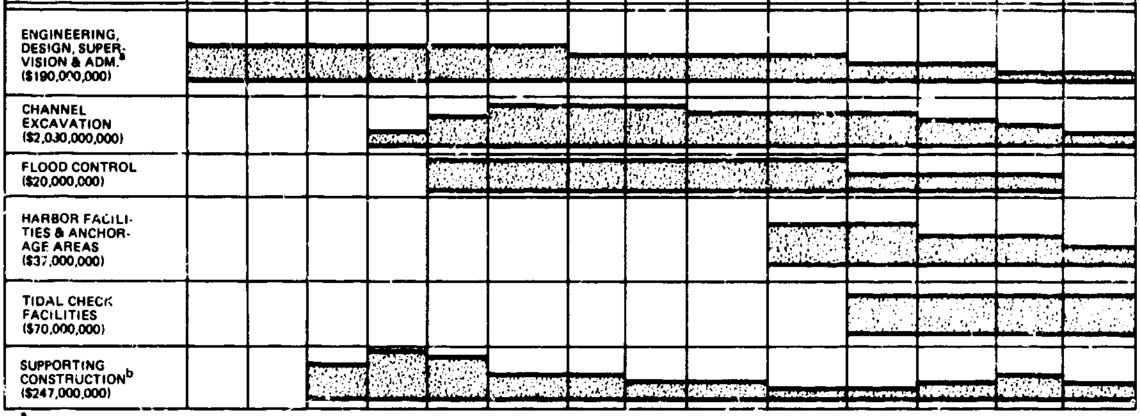
Zone and Panamanian authorities, since the success of the programs would depend in large part on existing parallel efforts carried on by these authorities. Costs associated with health and sanitation are estimated to be about $24 million.

- **Housing and related support requirements**: Facilities required for construction and operating personnel would include housing, utilities, and those needed to provide community services. During the construction phase, project personnel would be furnished housing comparable to that commonly available at long-term construction projects in the United States. Maximum use would be made of available housing in the Canal Zone and its immediate vicinity. Permanent facilities required for operating the canal, which also could be utilized during the construction phase, would be built so as to avoid duplication. Figure 20-5 includes possible sites for housing facilities. These communities would cost about $94 million.
- **Highways and bridges**: Provision would be made for a road network consisting of a transisthmian highway parallel to the alinement to assist in operating and maintaining the canal, and for secondary roads required during construction. The transisthmian highway would be an all-weather two-lane road running east of the alinement and crossing Gatun Lake on the barrier dam. It would be used to support both construction and subsequent operation and maintenance activities. A high-level highway bridge would be built at the Pan American Highway crossing of the sea-level canal. Neither large airfields nor permanent railroads would be included in the project. Figure 20-5 shows the proposed locations of the roadnet. The cost of providing it is estimated to be about $41 million.
- **Clearing and relocations**: The total cost of this item, $16 million, is attributable almost entirely to clearing, since few relocations are required on this route.
- **Operation and maintenance facilities**: Facilities (e.g., roads, bridges, and townsites) provided for construction would be used to the maximum extent practicable for the operation and maintenance of the sea-level canal. Additionally required operating facilities would include tugs, aids-to-navigation, communications and pilot facilities. A fleet of tugboats would be needed to assist larger ships in operating safely and to attain required transiting capacity. Maintenance facilities would include buildings, yards, and docks for supporting dredging operations and ship salvage. Hydraulic and mechanical dredges used in the construction phase would be utilized to the maximum extent possible as maintenance equipment. The total cost of new operating and maintenance facilities would be approximately $72 million.

Schedule: The schedule developed for the design and construction of a canal along Route 10 (Figure 20-6) provides a 2-year design phase preceding the start of construction. Preparatory work, such as clearing, relocations, highways, and initial construction of townsites and power distribution systems, would start about the beginning of the third year. Channel excavation would start at the beginning of the fourth year.

Personnel: Figure 20-6 also shows personnel requirements for the design and construction of a canal on Route 10. Personnel concerned with the operation of the canal after construction would be of two types: those who operate [illegible] and those who

YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14
ANNUAL COST ($ MILLIONS)	11	11	54	152	253	306	306	298	257	257	275	267	250	183
CUMULATIVE COST ($ MIL)	11	22	76	228	481	787	1093	1391	1648	1905	2180	2447	2697	2880
DESIGN AND CONSTRUCTION PERSONNEL	260	260	1160	2590	4100	4460	4460	4310	3790	3790	3780	3630	3390	2470
SUPPORT PERSONNEL	–	–	610	1630	2070	2150	2150	2110	2010	2010	2010	1970	1920	1060
TOTAL PERSONNEL	260	260	1770	4220	6170	6610	6610	6420	5800	5800	5790	5600	5310	3530



[a]Width of bar shows relative amount of activity for each major construction item.
[b]Includes roads, bridges, housing, clearing, relocations, area sanitation and health and operation and maintenance facilities.

ROUTE 10 COST, PERSONNEL AND CONSTRUCTION SCHEDULE

FIGURE 20-6

support its operation. Initially, the canal operating personnel would number 2,200 and the supporting group 890. Personnel requirements would grow with the number of transits as demands for traffic control, piloting, dredging, and tug services increase.

Cost summaries: The estimated cost of constructing a 36-mile single-lane canal with tidal checks on Route 10 is about $2.9 billion.

The costs of the principal elements are:

Channel excavation	$2,030,000,000
Flood control	20,000,000
Harbor facilities	37,000,000
Tidal checks	70,000,000
Supporting construction	247,000,000
Subtotal (rounded)	2,400,000,000
Contingency (12%)	290,000,000
Subtotal	2,690,000,000
Engineering, design, supervision, and administration (7%)	190,000,000
GRAND TOTAL	$2,880,000,000

Addition of a bypass to the basic plan would increase this figure by about $460 million to an estimated total cost of $3.3 billion.

A schedule of costs by year is shown in Figure 20-6.

Real estate: The basis for estimating the value of real estate acquisitions on all proposed routes has been discussed in Chapter 9. Most of the land required for Route 10 is owned by the Government of Panama, although some 2,000 people now occupy parts of it. The total value of necessary real estate rights for the approximately 100 square miles of land that would be permanently acquired, or through which permanent or temporary easements would be obtained, is estimated to be about $24 million. This amount is not included in the summary table.

Environmental changes: Construction of the canal would alter the ecology of the region from an upland, sparsely cultivated agricultural ecosystem to a more complex one, containing agricultural land, salt water and contact zone components. These changes, although drastic, are not expected to adversely affect the ecological balance or the ability of local inhabitants to utilize natural resources in the immediate area of the canal. Peripheral areas required for spoil and construction operation need be affected only temporarily, since encroachment of vegetation following construction would be very rapid in the tropical climate.

The net flow of sea water through a canal along Route 10, if tidal checks are not used, would average about 45,000 cubic feet per second* from the Pacific Ocean to the Atlantic. While this volume of water is probably too small to produce significant widespread changes in the physical characteristics of the marine environments, other potential effects deserve attention. The sea-level canal would provide a limited pathway for mixing biota from different ecosystems. Compared to the Pacific, the Atlantic system exhibits greater habitat diversity and, for certain groups of organisms, appears to have a richer fauna with more dominant competitive characteristics. Concern has been expressed that some species eventually might become extinct if a biotic barrier is not installed in the canal. Although not designed specifically as biotic barriers, tidal gates could reduce the net transfer of water between the oceans to nearly zero and could provide an effective, but not perfect, barrier. Even if no other mechanical barrier were installed, turbidity of the canal water and inflow of fresh water from the Caimito River and smaller streams could be expected to inhibit transisthmian migration of marine life.

Operation and maintenance costs: Fixed O&M costs for Route 10 would average about $35 million per year, with periodic fluctuations caused by replacement of major facilities. Variable O&M costs would be about $640 per transit, including the cost of operating the tug fleet. These costs may be combined into a single total annual operation and maintenance cost which, at 35,000 transits per year, would be $57 million.

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*By comparison, the average flow of the Missouri River past Kansas City is 55,000 cubic feet per second.

Operation with the Panama Canal: Operating Route 10 in conjunction with the Panama Canal offers several advantages. The lock canal could function initially as an alternate and eventually as a supplement to the sea-level canal. It would be advantageous to retain the Panama Canal in operable status until the stability of flood control structures and of the sea-level canal slopes seems reasonably assured. Although the risk of slides on Route 10 and the duration of resultant interference to traffic cannot be stated explicitly, the availability of the Panama Canal would greatly reduce their consequences.

Possibly more important than its availability in time of emergency would be the additional capacity that the lock canal could bring to a system including both the new and old routes. If ship transits were restricted indefinitely to currents of no more than 2 knots, limiting the capacity of Route 10 to about 38,000 annual transits, the Panama Canal could provide sufficient additional capacity to enable the system to meet requirements through the year 2040. Although capable of handling only ships smaller than 65,000 dwt, the Panama Canal could accommodate most of the ships passing through the system. Controlled scheduling would direct arriving ships to the appropriate canal for transit.

If Route 10 and the Panama Canal were incorporated into a single system, the two canals could operate as two divisions of one organization.

The ability of the Panama Canal to function effectively as a supplement to Route 10 far into the future depends on the useful life remaining to it. Its duration cannot be predicted. Now nearly 60 years old, the canal's locks have attained the age at which many engineering facilities are considered obsolete. There is no evidence, however, that the locks cannot continue in operation for several decades.

CHAPTER 21

ROUTE 14S

The alinement and general characteristics of Route 14S (Figure 21-1) have been discussed in Chapter 15.

Capacity: Three channel configurations have been considered for Route 14S. Each configuration includes the design channel between two-lane approach channels which have a 1,400- by 85-foot cross section. The bypass configuration adopted on Route 10 was not considered suitable for Route 14S because the topography precluded effective siting of a bypass. Expansion of the canal's capacity would be accomplished for the most part through progressive shortening of the single-lane section by extending the two-lane Atlantic approach across Gatun Lake. In order of increasing capacity and construction costs, the three configurations, identified by the length between approach channels, are:

- a 33-mile single-lane section;
- a 24-mile single-lane section; and,
- two parallel 19-mile single-lane sections.

All of these options would be constructed with tidal check gates to limit the maximum current of 2 knots. The location of the tidal checks would vary with the configuration and the acceptable maximum current velocities. Methods of operation with tidal checks located for a 2-knot maximum current are shown in Figures 21-2a, -2b, and -2c. Table 21-1 gives the capacity and cost data for the configurations at 2-, 3-, and 4-knot limiting currents. The capacity of the least costly alternative, with currents limited to 2 knots, would exceed the initial design criteria slightly. Other characteristics of the three options are compared in Table 21-2.

Based on the data and characteristics presented in the tables, the configuration preferred for initial construction on Route 14S would be with the 33-mile design channel and with tidal checks 24 miles apart to limit currents to 2 knots. Additional gate sills would be installed during construction to permit regulation of maximum currents at 3 or 4 knots, should experience show that a 2-knot limitation is too restrictive.* If navigation in a 4-knot current were found acceptable during actual operation, this configuration could provide a capacity approaching the 60,000 annual transit requirement for the year 2040. If, on the other hand, operation in currents over 2 knots were to prove unsafe, any capacity increase would have to come through additional construction or operational improvements not now foreseen.

*The optimal gate locations for both 3-knot and 4-knot current limitations are 33 miles apart at the ends of the one-way section.

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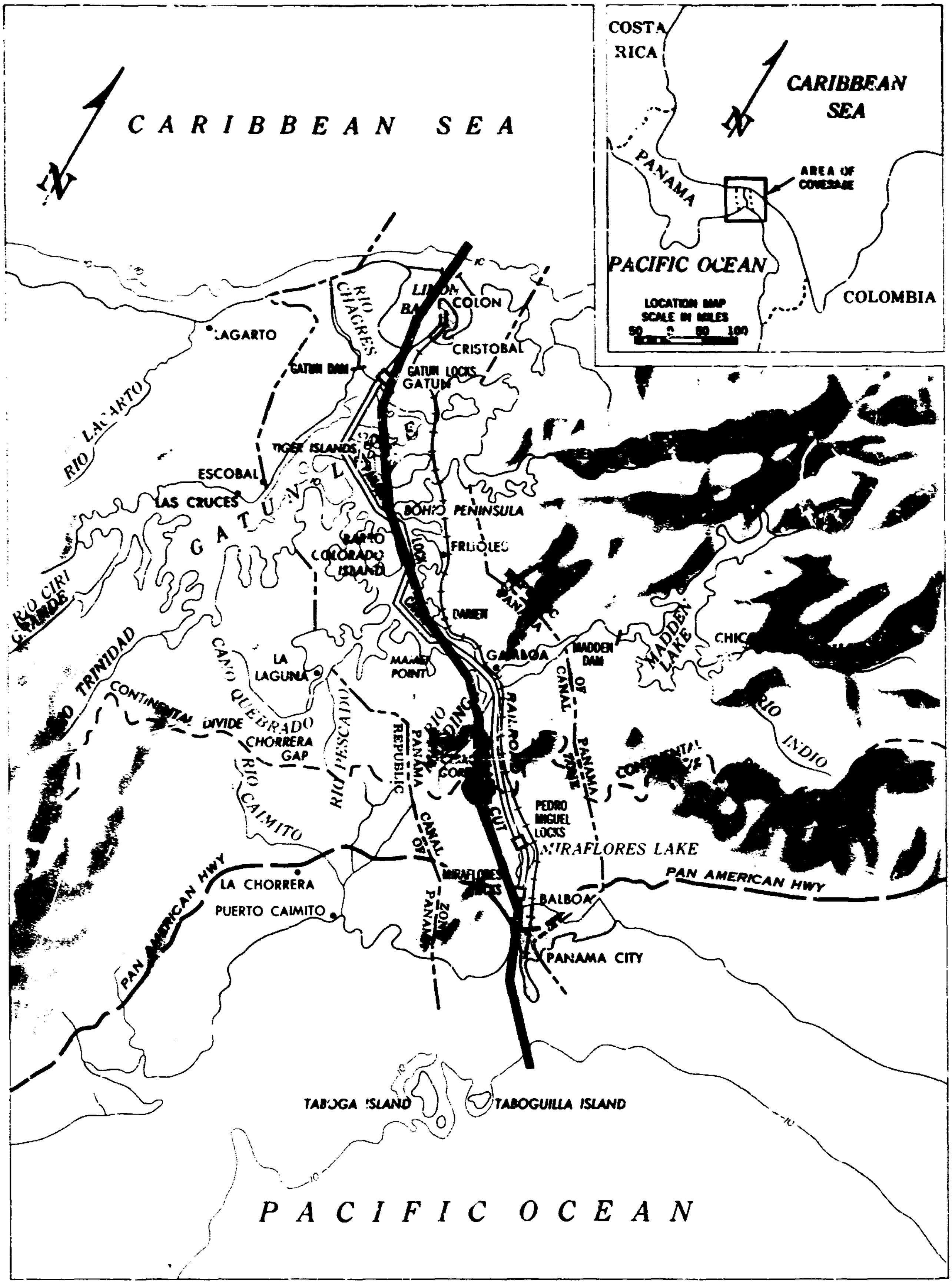
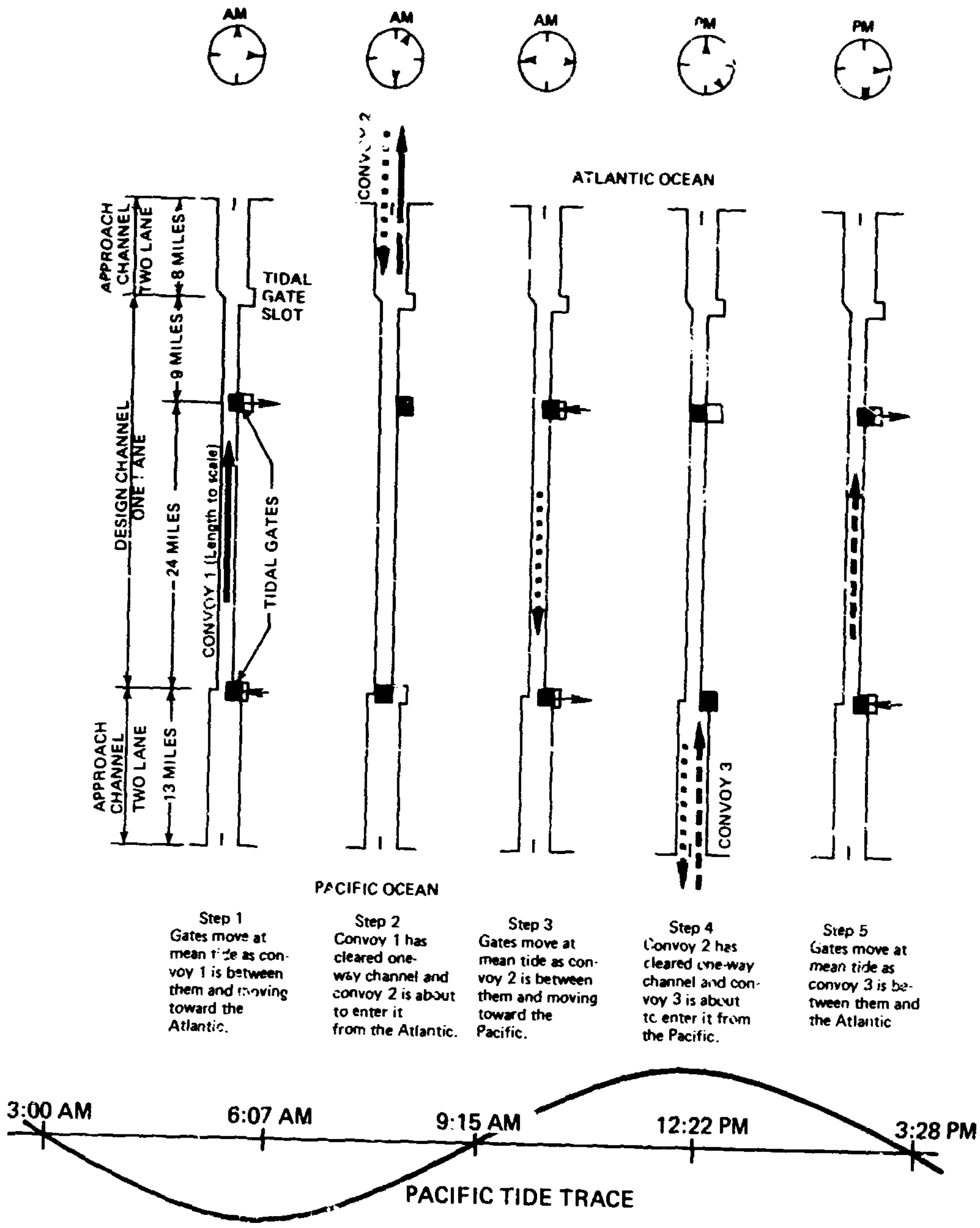


ROUTE 14 SEPARATE DIVIDE CUT

THE CANAL ZONE AND VICINITY

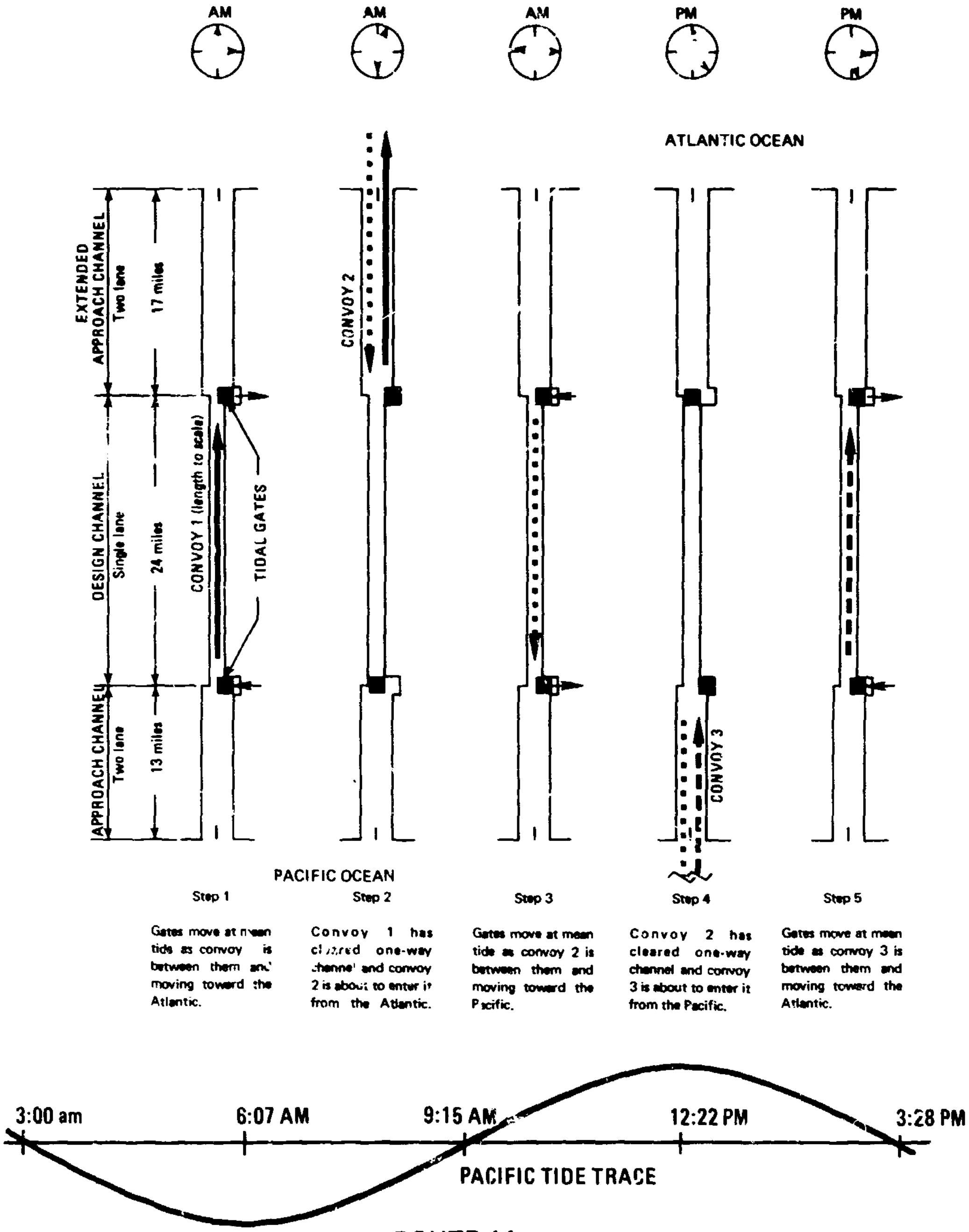
SCALE IN MILES
5 0 5 10
DEPTH IN FATHOMS

FIGURE 21-1



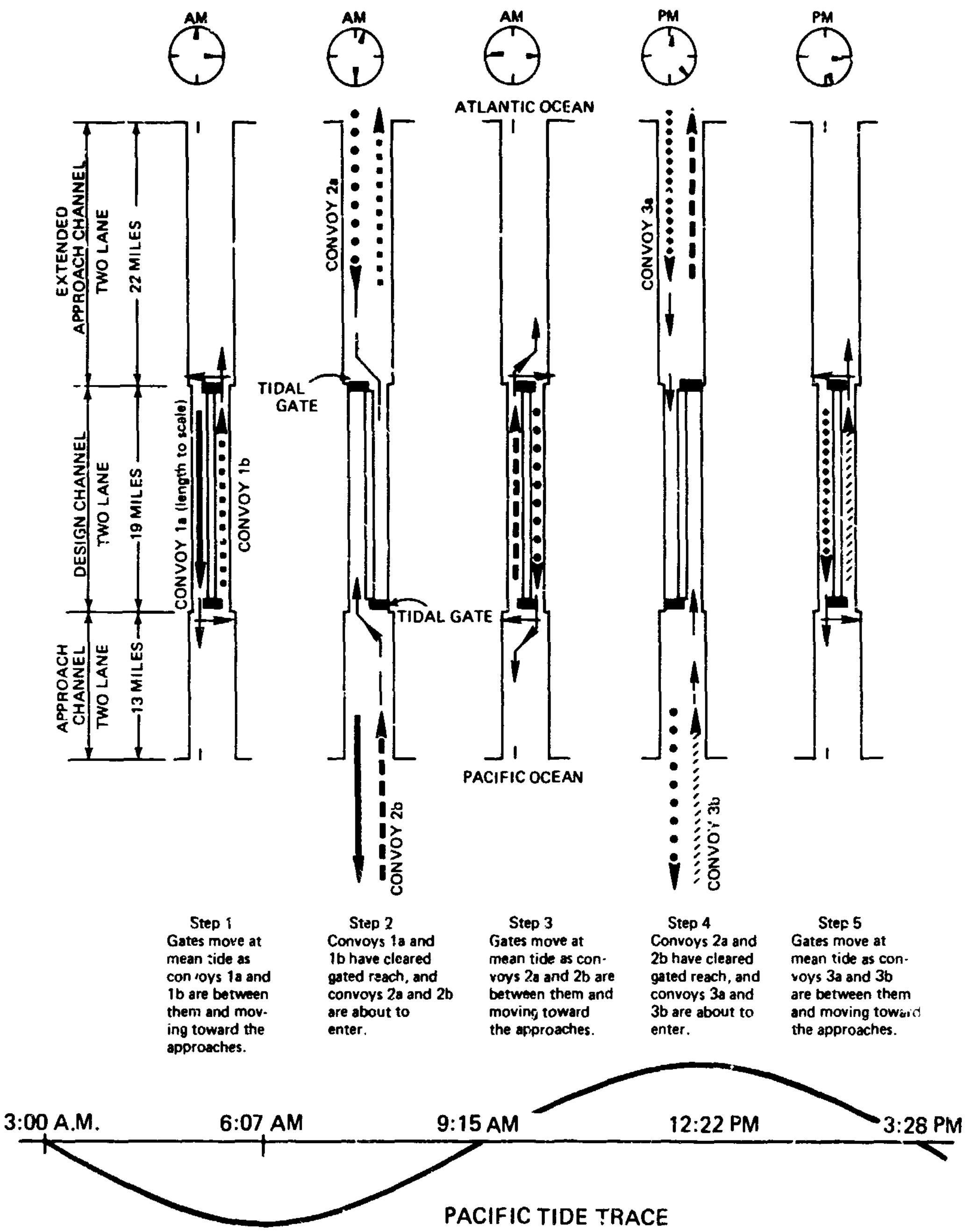
ROUTE 14
33-MILE SINGLE-LANE
PLAN OF OPERATION
2-KNOT ALLOWABLE CURRENT
12.4-HOUR CYCLE

FIGURE 21-2a



ROUTE 14
24-MILE SINGLE-LANE
PLAN OF OPERATION
2-KNOT ALLOWABLE CURRENT
12.4-HOUR CYCLE

FIGURE 21-2b



ROUTE 14
TWO-LANE
PLAN OF OPERATION
2-KNOT ALLOWABLE CURRENT
6.2-HOUR CYCLE

FIGURE 21-2c

TABLE 21-1

ROUTE 14S CAPACITY-COST DATA FOR DESIGN CHANNELS

Allowable Current and Configuration[a]	Annual Transits at 20 Hours Average TICW[b]	Average TICW[b] in Hours at Given Number of Transits Per Year: 35,000	60,000	100,000
2 knots:				
33 mi single-lane	39,000	9.9	c	c
24 mi single-lane	55,000	8.3	c	c
19 mi two-lane	82,000	6.1	6.3	c
3 knots:				
33 mi single-lane	42,000	15	c	c
24 mi single-lane	55,000	8.3	c	c
19 mi two-lane	82,000	6.1	6.3	c
4 knots:				
33 mi single-lane	59,000	12	23	c
24 mi single-lane	58,000	8.5	29	c
19 mi two-lane	113,000	4.9	4.9	12

Canal Configuration[a]	Estimated Construction Cost[d]	Design and Construction Time[d]	Fixed O&M Costs/Year[e]
33 mi single-lane	$3,040,000,000	16 years	$34,000,000
24 mi single-lane	430,000,000	4 years	33,000,000[f]
19 mi two-lane	1,670,000,000	7 years	40,000,000

[a]Configurations are given in length of design channel reach. Two-lane approaches at both ends are provided. Tidal gates are placed at optimum locations.
[b]TICW is the time spent in canal waters, a combination of waiting time and transit time.
[c]Capacities cannot be achieved for the stated configuration or require a TICW of over 40 hours.
[d]Costs and time for the 24-mile single-lane configuration are the additional costs and time over and above those for the basic 33-mile single-lane configuration. Costs and time for the 19-mile two-lane configuration are over and above those for the 24-mile single-lane configuration.
[e]Variable operation and maintenance costs would average about $640 per transit.
[f]The 24-mile single-lane configuration has lower costs because of improved efficiency.

TABLE 21-2
CHARACTERISTICS OF ROUTE 14S CONFIGURATIONS[a]

	33-mile Single-Lane Channel	24-mile Single-Lane Channel	19-mile Two-lane Channel
Capacity	Would slightly exceed initial requirements (35,000 transits per year).	Would approach year 2040 requirement. (60,000 transits per year).	Would exceed year 2040 requirement by a third.
Average time in canal waters (TICW)	9.9 hours at 35,000 annual transits.	8.3 hours at 35,000 annual transits.	6.1 hours at 35,000 annual transits.
Navigation	Ship speed must be set to match tidal check operation. Configuration requires the most travel in a one-lane reach, the least in a two-lane reach. Unchecked currents would be the least of the three configurations.	Ship speed must be set to match tidal check operations.	Ship speed must be set to match tidal check operation. Configuration requires the least travel in a one-lane reach and the most in a two-lane reach.
Flexibility of operation	Capacity, transit time, cycle time and TICW would be restricted by tidal check gate operation. Flexibility would improve with higher acceptable currents for navigation.	Capacity, transit time, cycle time and TICW would be restricted by tidal check gate operation.	Despite the need to use tidal gates, the complete two-lane capability makes this the most flexible of the three configurations.
Capacity at higher acceptable currents	Negligible increase at 3 knots, but a 4-knot limit with tidal checks would allow a capacity approaching the year 2040 requirement.	Increase in acceptable current velocity provides no significant capacity increase for this configuration. This configuration requires that tidal gates for 3- and 4 knot limiting currents be closer than optimum spacing.	Negligible increase at 3 knots, but 4-knot limit would provide a capacity of over 100,000 transits per year. This configuration requires that tidal gates for 3- and 4-knot limiting currents be closer than optimum spacing.
Expansion	Capacity could be increased 40% by extending approaches. Expansion work would entail some interference with transiting ships.	Capacity could be increased 50% by extending approaches and providing a dual channel. Expansion work would entail some interference with transiting ships.	No foreseeable need.

[a]Based on the design channel and, except where specifically stated, a maximum current of 2 knots. Tidal check gates would be in continuous use.

Geology: Route 14S is alined generally to take advantage of the low relief through which the Panama Canal was excavated. The divide cut has been moved southwesterly about 1 mile to avoid the weakened slopes of the Panama Canal and to lessen interference with existing canal traffic. Although shifting the alinement through this reach would increase excavation volumes over those for Route 14C, it would eliminate many of the problems of maintaining traffic in the existing canal throughout the excavation period.

The route crosses two major geologic areas. The first is an igneous complex, extending from the Bohio Peninsula in Gatun Lake across the Continental Divide to the Pacific coast. It consists of altered tuffs and agglomerates, but basalt flows and basaltic intrusions are common. Tuffaceous sandstones, limestones, and shales are found locally. In the area

northwest of the Bohio Peninsula and in the lower Chagres Valley, the lithology is considerably different, and consists of sedimentary sandstones of the Gatun and Caimito formations. In Gatun Lake the Caimito formation is overlain by Atlantic muck. Thick muck deposits also occur in the coastal lowlands and in shallows along both the Atlantic and Pacific approaches.

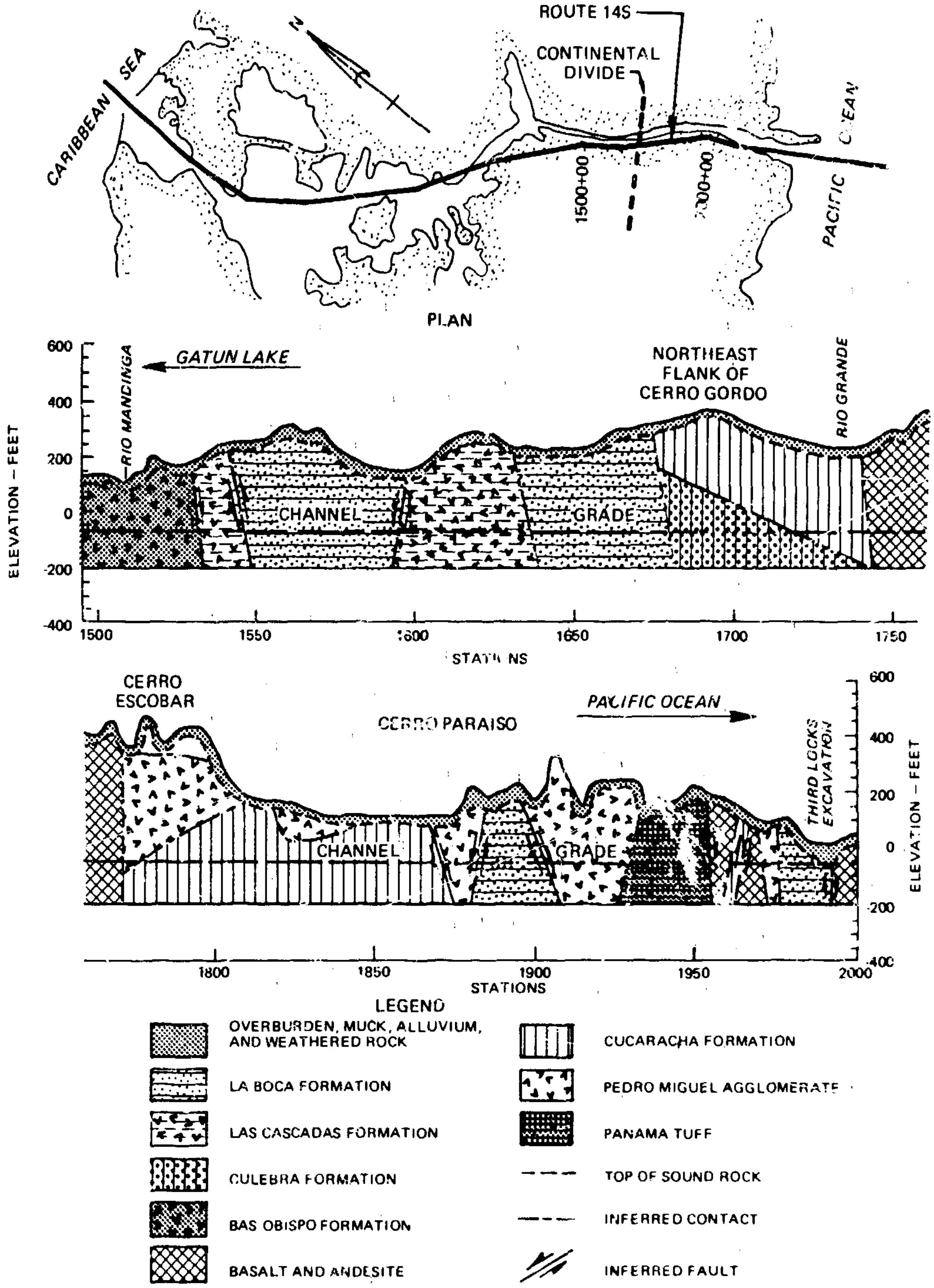
To locate the best alinement, extensive use was made of the Panama Canal Company records and previous studies, and a program of field explorations and geologic studies was conducted. The program was concentrated in the Continental Divide reach which entails 60 percent of the total excavation and where the most difficult problems associated with geologic structure and lithology would be encountered. Geologic formations with a history of slides were sampled and tested to determine their physical properties for use in studies of slope stability during and after excavation. Particular attention was given to the Cucaracha and the Culebra formations in which numerous slope failures occurred during construction of the Panama Canal. Cerro Gordo, an isolated peak rising to an elevation of 958 feet and forming a portion of the divide, was also studied in considerable detail. The Route 14S alinement, as shown on Figure 21-1, passes close to it. Excavation along the route would require removal of about 300 million cubic yards of material from the north and northeastern flanks of Cerro Gordo to preclude the possibility of massive slides capable of blocking the canal. The alinement uses the excavations made as part of the Third Locks project at Gatun and Miraflores. A geologic profile of the divide cut is shown on Figure 21-3.

The most critical reaches of the divide are from Station 1650 to Station 1740, adjacent to Cerro Gordo, and from Station 1780 to Station 1870, adjacent to Cerro Paraiso. In these areas the Cucaracha clay shales are either exposed or underlie more competent basalts and the Pedro Miguel agglomerates. The Cucaracha clay shales are noted for their poor stability under high slopes and they have low residual friction angles (4 to 10 degrees). Relatively high terrain within the limits of the excavation, complicated structure, and the Cucaracha clay shales would present continuing threats to the stability of canal banks. To attain stable conditions in these areas, initial slopes flatter than one vertical on ten horizontal might be required.

Field explorations showed that a fault cuts diagonally through Cerro Gordo and that the northeastern half of the hill is underlain by Cucaracha clay shales at depths shallow enough to affect slope stability. The remainder of the hill is considered stable. Exploration also indicated that Cerro Paraiso is underlain and flanked by the Cucaracha formation and that most of this hill must be removed to conform to established soft rock slope criteria.

Geologic conditions are more favorable and elevations are relatively low in the remainder of the divide reach. From Station 1500 to Station 1650, Las Cascadas agglomerates and the La Boca formation are encountered. Both are low quality rocks for slope design purposes, but they do not present serious problems because cuts in this reach would be less than 300 feet deep.

Between Stations 1750 and 1770 is a reach of competent basalt and agglomerate which would permit the use of slope criteria for high quality hard rock. The divide areas beyond Station 1870 lie generally below 200 feet and much of the excavation would be in high quality intrusive basalts. Several deposits of the La Boca formation would be exposed, however, and slope criteria for rock of low quality would have to be used.



GEOLOGIC PROFILE CONTINENTAL DIVIDE
ROUTE 14 SEPARATE
FIGURE 21-3

From the Atlantic end of the divide reach, about Station 1500, to the Bohio Peninsula, Station 780, elevations average about 100 feet with several hills as high as 300 feet. Formations in this area include the Bohio, the Caimito, and the Bas Obispo, all of which have been intruded by basaltic dikes. Excavation experience with these rocks along the canal has been favorable. All are of high or intermediate quality, capable of maintaining steep slopes.

The alinement from Bohio Peninsula across Gatun Lake to the Atlantic approach cuts through the tuffaceous sandstone, shales, and tuffs of the Caimito; siltstones; tuffs of the Gatun formation; Bohio conglomerates; and igneous intrusions. All of these formations are classified as intermediate quality rocks, and experience with the Third Locks cut in the Gatun formation indicates that the application of intermediate quality rock slope criteria to them would be appropriate. Elevations are low throughout this region of stratified rock.

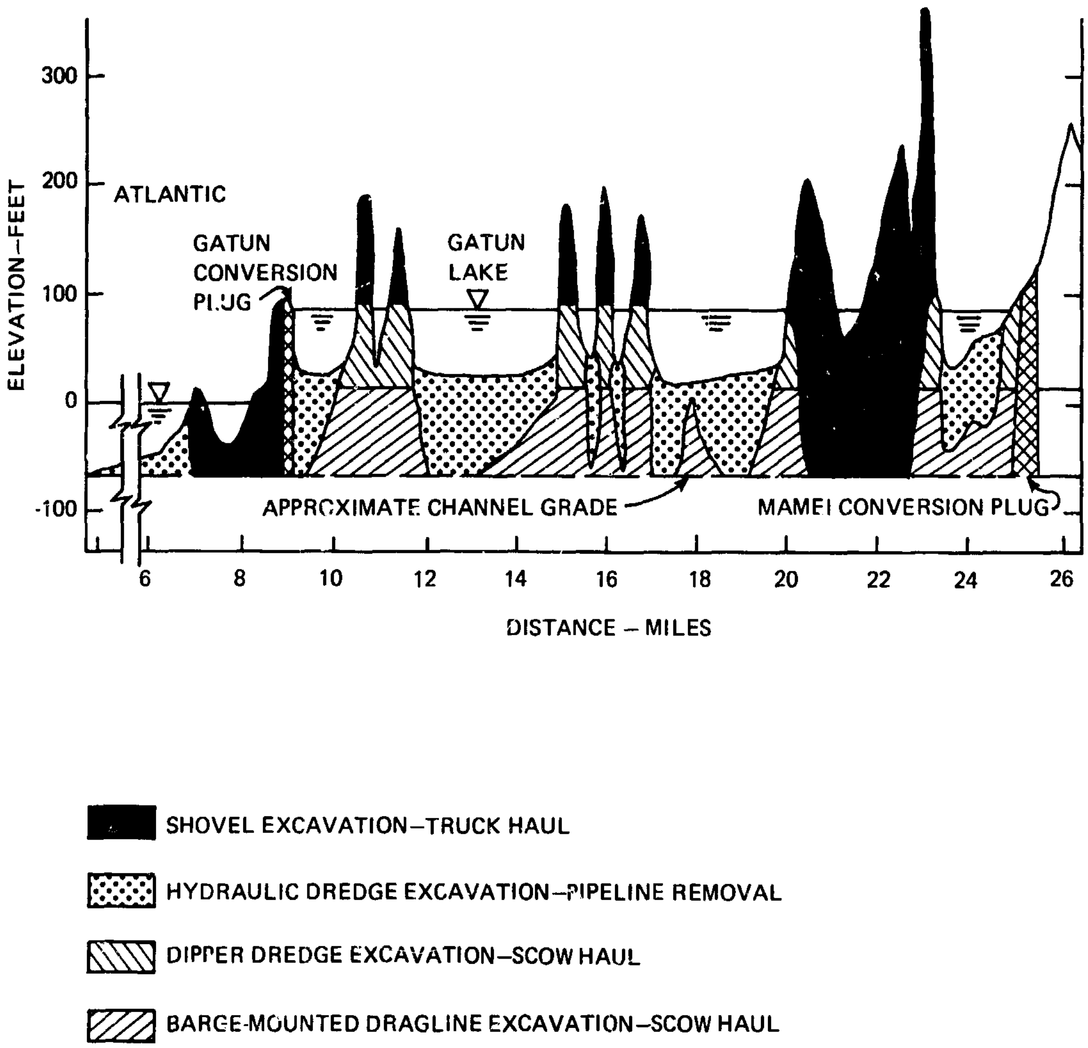
Muck has been deposited to depths of over 225 feet in the old river channels of the Chagres River which are incised in the Caimito formation in the area now inundated by Gatun Lake. Muck is also found along the Pacific coastal plain, where it reaches depths of over 50 feet, and along the Atlantic shoreline. Extremely flat slopes would be required in these unconsolidated sediments wherever they lie above water level.

Excavation: The total quantities excavated along Route 14S would amount to about 1,950,000,000 cubic yards. The excavation has been divided into two reaches for analysis – the first through Gatun Lake, and the second through the divide. The requirement to maintain navigation in the Panama Canal during the construction period would limit the flexibility of operations along both reaches.

Across Gatun Lake the canal could be constructed by using dredges working from the regulated lake level (average 85 feet), or by excavating mostly in the dry within areas isolated by large cofferdams. Of these alternatives, the deep dredging plan presents the fewest uncertainties, and has been adopted as the primary system in estimating the cost of excavating the Gatun Lake reach. The systems considered suitable for this reach are shown on Figure 21-4.

Muck would be removed from Gatun Lake down to depths as great as 170 feet below the surface using 48-inch hydraulic pipeline dredges operating from the +85-foot lake level. On the islands and peninsulas a shovel/truck haul system would be used to remove as much material as possible in the dry. The remaining rock would be excavated in two phases. In the first, dipper dredges would remove the material between elevations +90 and +15 feet. Then 35-cubic-yard barge-mounted draglines would excavate the remaining material to channel grade. Excavated material would be hauled in bottom dump scows to spoil disposal areas in Gatun Lake. Rock plugs would be left in the cut at either end of the lake to maintain the water level until canal operations are converted to sea-level.

Massive flood control dams would be constructed with suitable material excavated from the Gatun Lake reach. A layer of select material would be spread first to form a blanket over the existing muck, after which spoil would be placed in successive underwater lifts to an elevation +65 feet. The dams would be built with very flat slopes averaging about 1 vertical on 35 horizontal. After Gatun Lake is drawn down during the transition from lock canal to sea-level canal operation, the crests of the dams would be raised to elevation +73 feet. After the transition, the dams would maintain the remaining parts of Gatun Lake



PROFILE-GATUN LAKE REACH–ROUTE 14 SEPARATE

FIGURE 21-4

at elevation +55 feet. The cost of placing the dams would not be significant because their construction would provide the most economical way to dispose of spoil excavated from Gatun Lake and the adjacent divide cut reach. A typical cross section of the dams is shown on Figure 21-5. Their location is shown on Figure 21-1.

Through the divide reach the alinement is separated from the existing canal. This permits effective use of a combination of excavation systems to achieve least cost. A generalized excavation plan suitable for this reach is shown in Figure 21-6. Initial efforts would involve lowering the hilltops along the alinement using truck haul since grades would be too steep and distances too short for rail. As excavation at the higher levels is completed and cuts are opened, truck haul would be replaced by rail haul. A shovel/rail haul system would then be used down to elevation +90 feet for the 6 miles at the northwestern end of the 13-mile reach and down to elevation +15 feet for the remainder. These bench elevations and station limits were chosen to permit economical layout of the rail lines and to provide sufficient material to construct the flood control dams in Gatun Lake. A dipper dredge/scow haul system operating from the Gatun Lake level would move material from the 6-mile reach between elevations +90 feet and +15 feet to the dam sites. A plug would then be constructed near Mamei Point and the reach would be drained. Dipper dredges would complete the cut from elevation +15 feet to project depth, working in from the Pacific Ocean. Excavated materials would be hauled by bottom dump scows to spoil areas in the ocean.

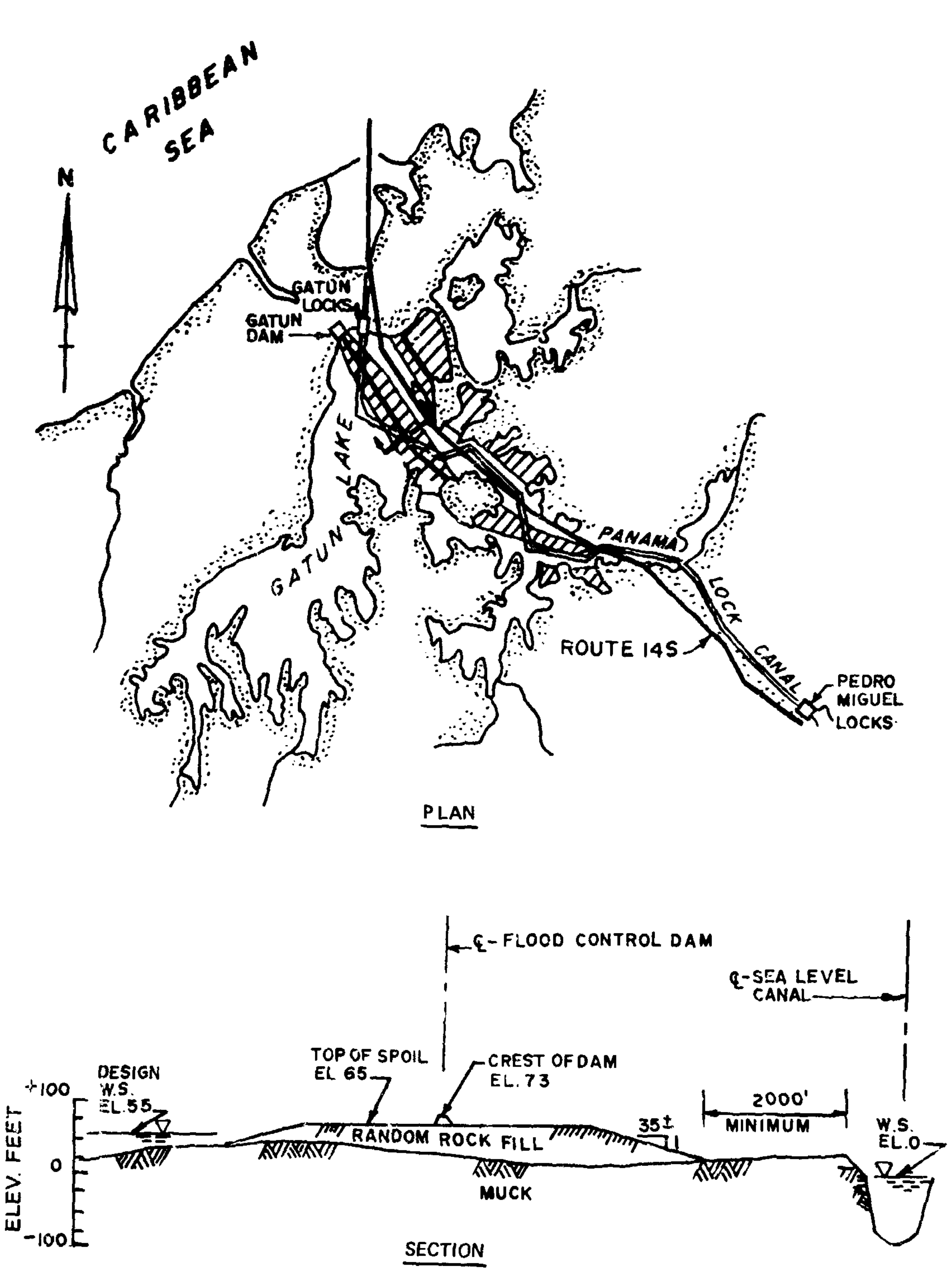
Hydraulic cutterhead dredges would remove the preblasted soft rock from the Atlantic approach. On the Pacific side, hopper dredges would excavate the soft materials, while the barge-mounted draglines would be used for harder materials.

Estimated excavation quantitites are shown in the following table:

Type of material	Cubic yards	Percent
Common	470,000,000	24
Soft rock	565,000,000	29
Medium rock	390,000,000	20
Hard rock	525,000,000	27
TOTAL	1,950,000,000	100

The total cost of excavation would be about $2.2 billion.

Spoil disposal areas: Maximum use of land disposal areas is planned, except for the use of spoil to construct dams in Gatun Lake. Where topographic conditions permit, upland spoil disposal areas would be located adjacent to the canal alinement at a minimum distance of 2,000 feet from the top of excavated slopes. Virtually unlimited area is available for spoil disposal, except as restricted by the length of haul and the grades encountered. Ocean disposal would be minimized because of haul lengths, occasional rough seas, and possible interference with shipping.



ROUTE 14 SEPARATE– FLOOD CONTROL DAMS

ROUTE 14 SEPARATE–FLOOD CONTROL DAMS

FIGURE 21-5

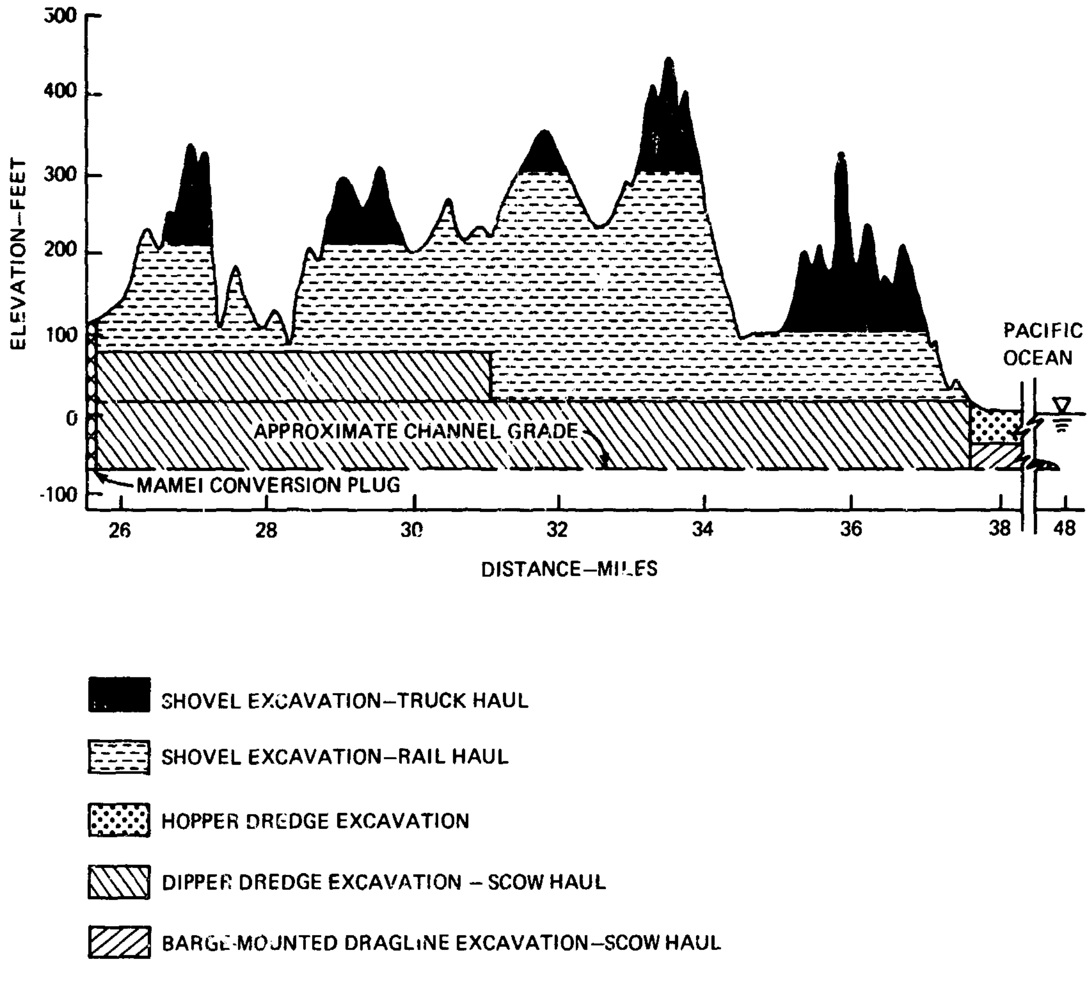
Stream diversion: The construction plan for Route 14S calls for lowering Gatun Lake as far as possible without creating a large, potentially unhealthy inland swamp. An elevation of 55 feet would meet these requirements at minimum project cost. Separate reservoirs would be formed on either side of the canal alinement by the flood control dams. The reservoir on the west side would control the Trinidad and Ciri Rivers (drainage area 327 square miles), while that on the east side would control the Gatun River (drainage area 166 square miles). Both reservoirs would discharge into the Caribbean Sea. The Pedro Miguel Locks, Miraflores Locks, and Miraflores spillway would be modified to serve as flood control structures, handling the flow from the 540-square-mile drainage area of the Chagres River which would be diverted down the alinement of the existing canal to discharge into Balboa Bay. The Caño Quebrado and its tributaries (183 square miles) would be discharged through an inlet structure into the canal. Figure 21-7 shows the major stream diversion facilities, which would cost about $30 million.

Harbor facilities: Only a limited expansion of the port and harbor facilities existing at Cristobal and Limon Bays on the Atlantic and Panama City and Balboa Harbor on the Pacific would be required. The additional facilities would consist of anchorage areas at each end of the canal dredged to the project depth of 85 feet to accommodate deep draft ships. The two existing Canal Zone ports are well developed and could serve as depots supplying the various services essential to shipping, such as repairing and bunkering. The general locations of needed facilities are shown in Figure 21-7; their cost would be about $12 million.

Tidal checks: Cost estimates include the construction and use of tidal checks. Their design would be identical to those discussed previously. They are estimated to cost approximately $70 million, including below-water construction for the alternate current limitation options.

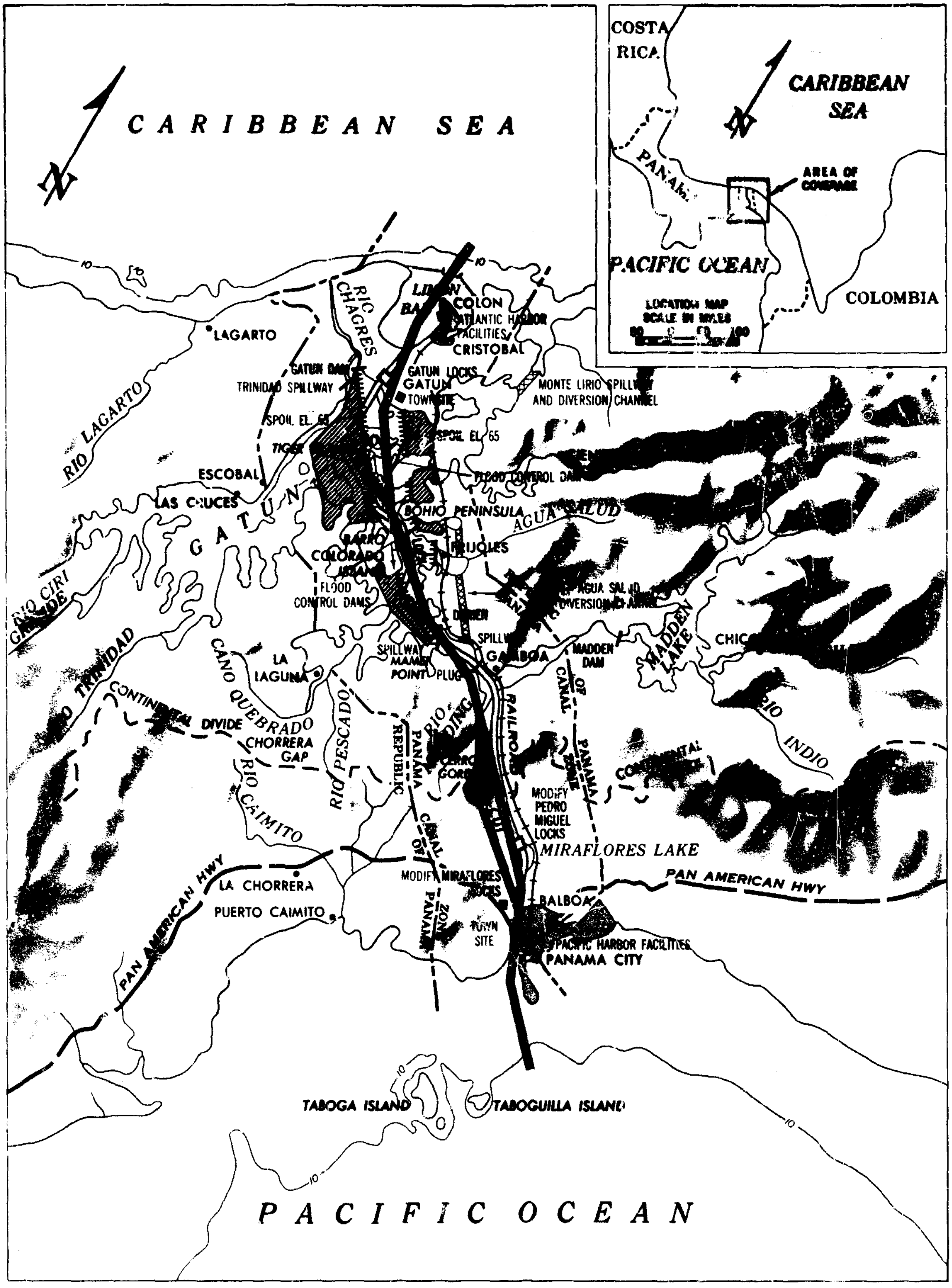
Conversion: A specially planned and executed sequence of operations lasting from one to three months would be required to lower Panama Canal operating water levels to sea level and to open the sea-level canal for traffic. In this conversion period, two plugs (one at either end of Gatun Lake) would be removed to allow the water level between the flood control dams in Gatun Lake to be drawn down to sea level. Miraflores Lake and the remainder of Gatun Lake would be lowered to +55 feet during this time. Concurrently, in the old lock canal channel, an earth plug would be constructed near Gamboa to divert the Chagres River. Throughout the drawdown period, all slopes would be observed closely to detect incipient slides caused by the lowering of the water level and the effect of salt water on the slopes. Figure 21-8 illustrates the sequence of conversion operations, which are estimated to cost about $3 million.

Supporting construction: Items required to support the main construction effort would include health and sanitation facilities, housing, highways and bridges, clearing and relocations, and facilities needed for the operation and maintenance program. The total cost of these items would be about $219 million.



PROFILE–DIVIDE REACH–ROUTE 14 SEPARATE

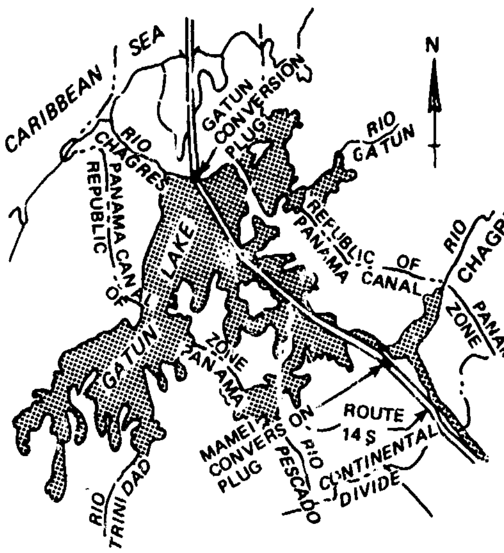
FIGURE 21-6



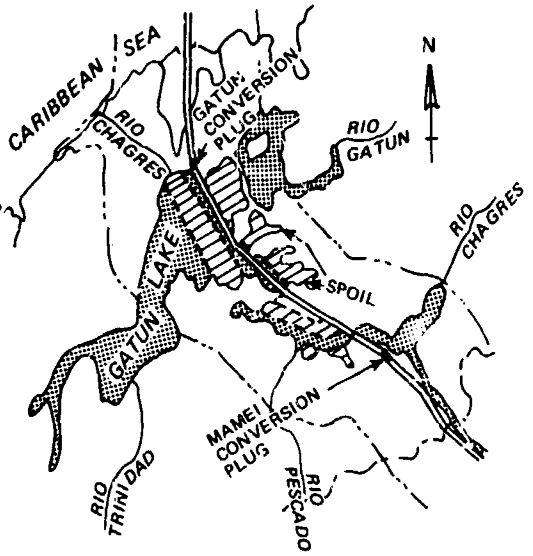
ROUTE 14 FLOOD CONTROL AND SUPPORT FACILITIES
THE CANAL ZONE AND VICINITY

SCALE IN MILES
5 0 5 10
DEPTH IN FATHOMS

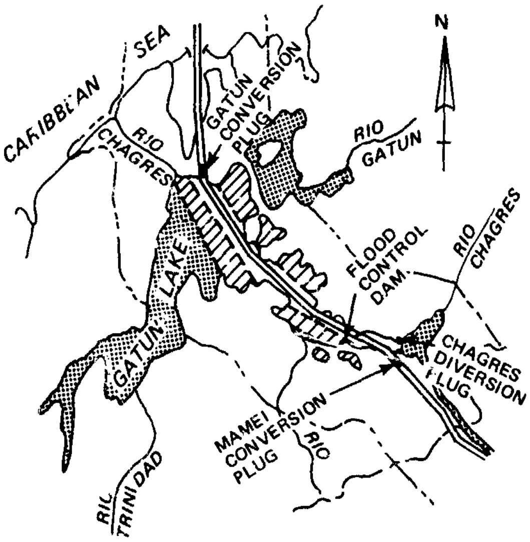
FIGURE 21-7



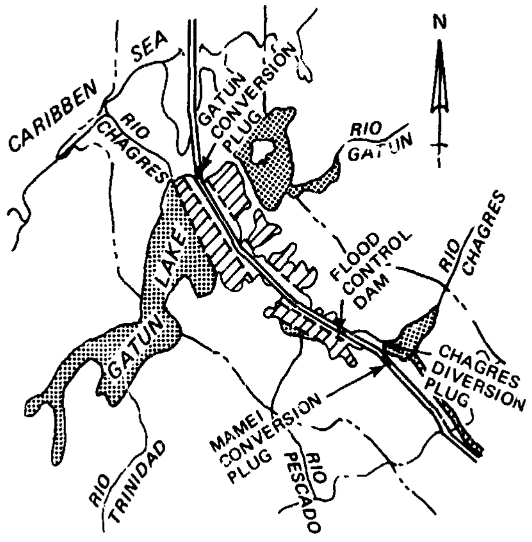
a. START OF CONVERSION
Lock canal abandoned. Water in Gatun and in sea-level cut between conversion plugs at el. 85.



b. 5 TO 15 DAYS
Water in Gatun Lake and sea-level cut between conversion plugs has been drawn down to el. 55. Spoil at el. 65 shows above Gatun Lake water surface as flood control dams.



c. 15 T' 30 DAYS
Water in sea-level canal drawn down to sea level, water in Rio Pescado and Rio Chagres drawn down to el. 40. Chagres diversion plug partially closed. Initial cut through Mamei conversion plug partially removed.



d. 30 TO 90 DAYS
Initial cut through conversion plugs and construction of Chagres diversion plug completed. Sea-level canal ready for traffic.

ROUTE 14 SEPARATE SEQUENCE OF CONVERSION

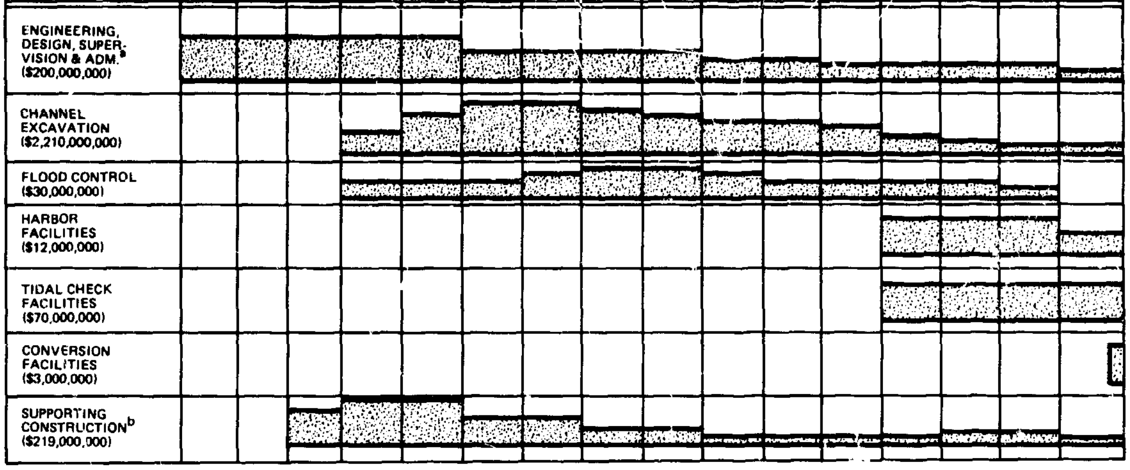
FIGURE 21-8

- **Health and sanitation**: The requirements for health and sanitation measures on Route 14S, and the program to provide them, are similar to those of Route 10. The total cost for health and sanitation programs would be about $27 million.
- **Housing and related support requirements**: Housing and related requirements would be essentially the same as for Route 10. The total cost of these facilities for Route 14S would be approximately $110 million. Their proposed locations are shown on Figure 21-7.
- **Highways and bridges**: The existing road network would be adequate. The Thatcher Ferry Bridge on the Pan American Highway would provide the necessary canal crossing.
- **Clearing and relocations**: Requirements for clearing are similar to those of Route 10. A number of minor relocations of utilities would be necessary; however, the existing railroad would not have to be relocated, since it probably would be abandoned upon completion of the sea-level canal, if not before. The total cost of this item would be about $16 million.
- **Operation and maintenance facilities**: The need for constructing new facilities for operating and maintaining the sea-level canal along Route 14 would be minimal. Facilities provided to support the construction effort would be used to the maximum extent possible, as would all existing facilities of the lock canal. Requirements would be similar to those for Route 10 except that new pilot facilities would not be needed. Maintenance facilities of the dredging division now located at Gamboa, would have to be moved. The total cost of operation and maintenance facilities along this route would be about $66 million.

Schedule: A schedule under which this work could be accomplished is shown in Figure 21-9. It includes a 2-year preconstruction phase. This schedule is based on the assumption that work on preparatory items, such as clearing, relocations, highways, and initial construction of townsites and power distribution systems would start immediately thereafter. Another year has been allowed for preparatory work, including mobilization of equipment, before excavation begins.

Personnel: Manpower requirements for design and construction, including both government and contractor personnel, are shown on Figure 22-9. Requirements for personnel to operate the canal would be similar to those for Route 10. Initially, total operating and support personnel would number 3050.

YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
ANNUAL COST ($ MILLION)	11	11	40	179	321	366	364	317	284	262	250	215	140	121	91	68
CUMULATIVE COST ($ MIL)	11	22	62	241	562	928	1292	1609	1893	2155	2405	2620	2760	2881	2972	3040
DESIGN AND CONSTRUCTION PERSONNEL	260	260	1000	3110	4910	5110	5110	4520	4100	3600	3430	2940	1980	1760	1340	1160
SUPPORT PERSONNEL	–	–	400	1860	2240	2280	2280	2160	2070	1970	1930	1700	1140	1100	1000	610
TOTAL PERSONNEL	260	260	1400	4970	7150	7390	7390	6680	6170	5570	5360	4640	3120	2860	2340	1770



[a]Width of bar shows relative amount of activity for each item.
[b]Includes area sanitation and health, townsites, clearing and relocations, and the construction of operation and maintenance facilities.

ROUTE 14S COST, PERSONNEL AND CONSTRUCTION SCHEDULE

FIGURE 21-9

Cost summaries: The total construction cost of the Route 14S configuration with a 33-mile, one-way channel and tidal checks is estimated to be about $3 billion. The principal elements of this total and their costs are:

Channel excavation	$2,210,000,000
Flood control	30,000,000
Harbor facilities	12,000,000
Tidal checks	70,000,000
Conversion facilities	3,000,000
Supporting construction	219,000,000
Subtotal (rounded)	2,540,000,000
Contingency (12%)	300,000,000
Subtotal	2,840,000,000
Engineering, design, supervision, and administration (7%)	200,000,000
GRAND TOTAL	$3,040,000,000

A schedule of costs by year is shown in Figure 21-9.

Real estate: The basis for estimating the value of real estate acquisitions on all the proposed routes has been discussed in Chapter 9. The total value of the approximately 110 square miles of land required along Route 14S is estimated to be about $2 million, based on resource value, without considering treaty rights. All of this land lies within the present boundaries of the Canal Zone. The small tracts in private hands are essentially unimproved.

Environmental effects: A sea-level canal on the Route 14S alinement would produce ecological effects similar to those that might be expected on Route 10. The one significant difference involves Gatun Lake. The 30-foot drop in surface elevation would reduce the total water surface area from 165 to about 62 square miles subdivided into several smaller lakes. (See Figure 21-7). Most of the reclaimed land would soon revert to tropical forest. The quantity and diversity of flora and fauna of the lake would be reduced; however, losses are not expected to be significant, since several large portions of the lake would be capable of sustaining viable populations of most organisms now existing there.

Operation and maintenance costs: Costs of operation and maintenance on Route 14S would be similar to those of Route 10. For 35,000 annual transits, these costs would be approximately $56 million per year.

CHAPTER 22

ROUTE 25

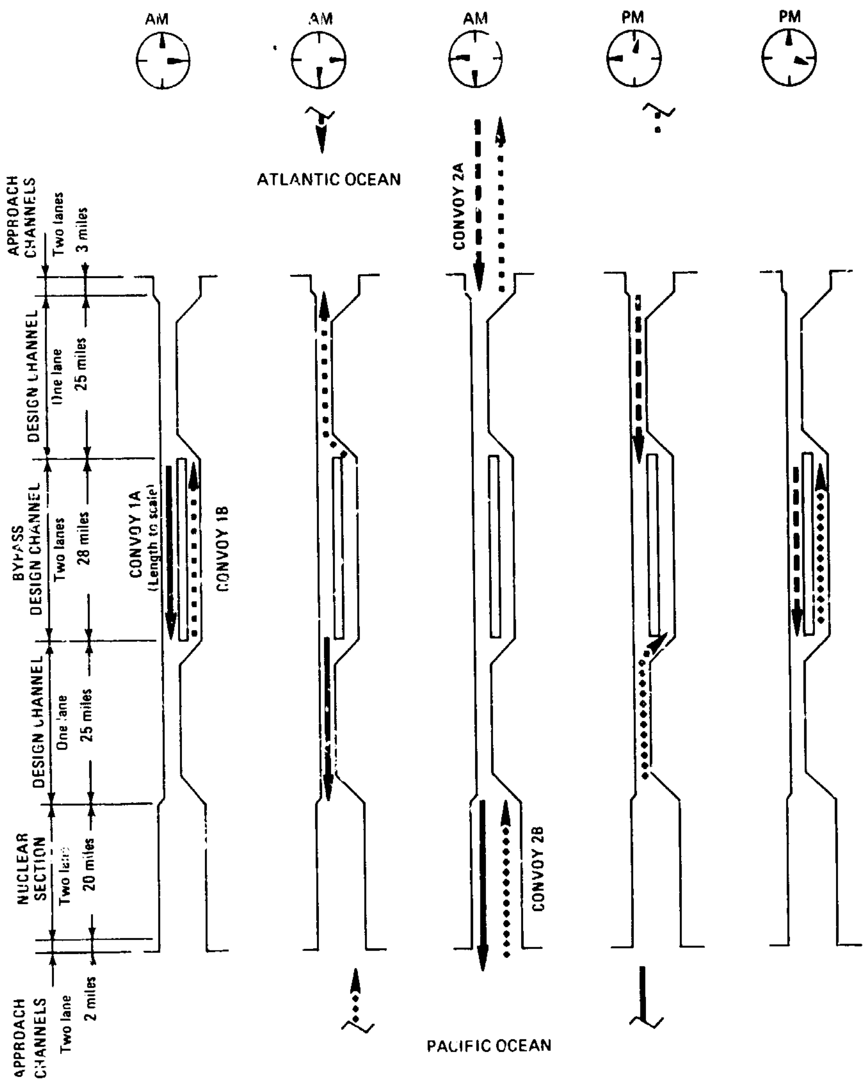
Throughout the following discussion of Route 25, it is assumed that nuclear excavation would be feasible, that it would be politically acceptable and that it would entail costs and produce results generally as described in Appendix 3 (Nuclear Excavation Technology). The testing program required to prove or disprove the validity of these assumptions has been outlined in Chapter 6 and is presented in detail in Appendix 3. The general features of Route 25 (Figure 18-1) were described in Chapter 18.

Capacity: Two configurations for Route 25 were considered; both include a 78-mile conventionally excavated design channel; a 20-mile 1,000-foot wide nuclear excavated channel; and 5 miles of two-lane 1,400- by 85-foot approach channels. The basic configuration includes a 28-mile conventionally excavated bypass needed to attain the minimum required transiting capacity without excessive TICW. The expansion configuration would provide two-lane navigation over the entire length of the canal making convoy operation unnecessary. Figure 22-1 shows how the bypass would operate. Table 22-1 gives capacity-cost data for the two configurations.

A canal unobstructed by tidal checks appears more acceptable and desirable on Route 25 than on Routes 10 and 14S for several reasons:

- The length of Route 25 and the smaller tidal range of the Pacific at this site limit peak tidal current velocities to about 3 knots.
- In the nuclear excavated section, the large channel cross section would reduce currents to less than 1 knot.
- Along most of the conventionally excavated reach, where highest current velocities would occur, the canal banks would be soft and not likely to damage a ship running aground.
- The capacity of the route with a 3-knot limiting current exceeds the 60,000 annual transit requirement for the year 2040, so that operations in peak currents could be avoided without significant impact on capacity by scheduling transits to avoid currents stronger than 2 knots.
- Ships larger than 25,000 dwt would be assisted through the canal by tugs.
- The length of Route 25 would make it a very effective biotic barrier, even without tidal gates.

For these reasons tidal checks have not been included in conceptual designs made for this study, despite the fact that currents would exceed the 2-knot maximum current limitation imposed on Routes 10 and 14.



Convoys 1A and 1B are in the bypass section about to enter the one-lane sections.

Step 2

Convoys 1A and 1B are in the one-way sections about to enter the two-lane sections at canal ends

Step 3

Convoys 1A and 1B are in the two-lane end sections moving seaward. Convoys 2A and 2B are in the two-lane end sections about to enter the one-lane sections.

Convoys 2A and 2B are in the one-lane section about to enter the bypass section.

Step 1

Convoys 2A and 2B are in the bypass section about to enter the one-way sections.

ROUTE 25
BYPASS
PLAN OF OPERATION
3-KNOT ALLOWABLE CURRENT
13-HOUR CYCLE

FIGURE 22-1

TABLE 22-1

ROUTE 25 CAPACITY-COST DATA FOR DESIGN CHANNELS

Configuration[a]	Annual Transits at 20 Hours Average TICW[b]	Average TICW[b] in Hours at Given Number of Transits Per Year		
		35,000	60,000	100,000
3 knots:				
Bypass	65,000	16	17	c
Two-lane	268,000	12	12	12

Canal Configuration[a]	Estimated Construction Cost[d]	Design and Construction Time[d]	Fixed O&M Cost/Year[e]	Net Flow (cfs)
Bypass	$2,100,000,000	13 years	$49,000,000	30,000
Two-lane	$ 630,000,000	5 years	$60,000,000	60,000

[a]Bypass designates a single-lane design channel with one 28-mile bypass. Two-lane designates two parallel 78-mile single-lane channels. Both configurations have a two-lane 20-mile nuclear excavated channel at the Pacific end. Both configurations would operate within a 3-knot current limitation.

[b]TICW is time in canal waters, a combination of waiting time and transit time.

[c]Transit capacity indicated cannot be achieved.

[d]Costs and construction times indicated for the two-lane configuration represent additional costs and times over and above those for the bypass configuration.

[e]Variable operation and maintenance costs would average about $1,000 per transit.

Table 22-2 summarizes the characteristics of the two Route 25 options. The less costly bypass configuration is preferred. Its capacity is estimated to be 65,000 transits per year, and it would provide an excellent basis for expanding to a full two-lane capability if the need to do so should arise.

Geology: The economic feasibility of Route 25 depends on the stability of slopes formed by nuclear excavation in the divide and on the anticipated ease of excavating across the Atrato flood plain with hydraulic pipeline dredges. The geology along the final alinement is shown in Figure 22-2.

TABLE 22-2
CHARACTERISTICS OF ROUTE 25 CONFIGURATIONS[a]

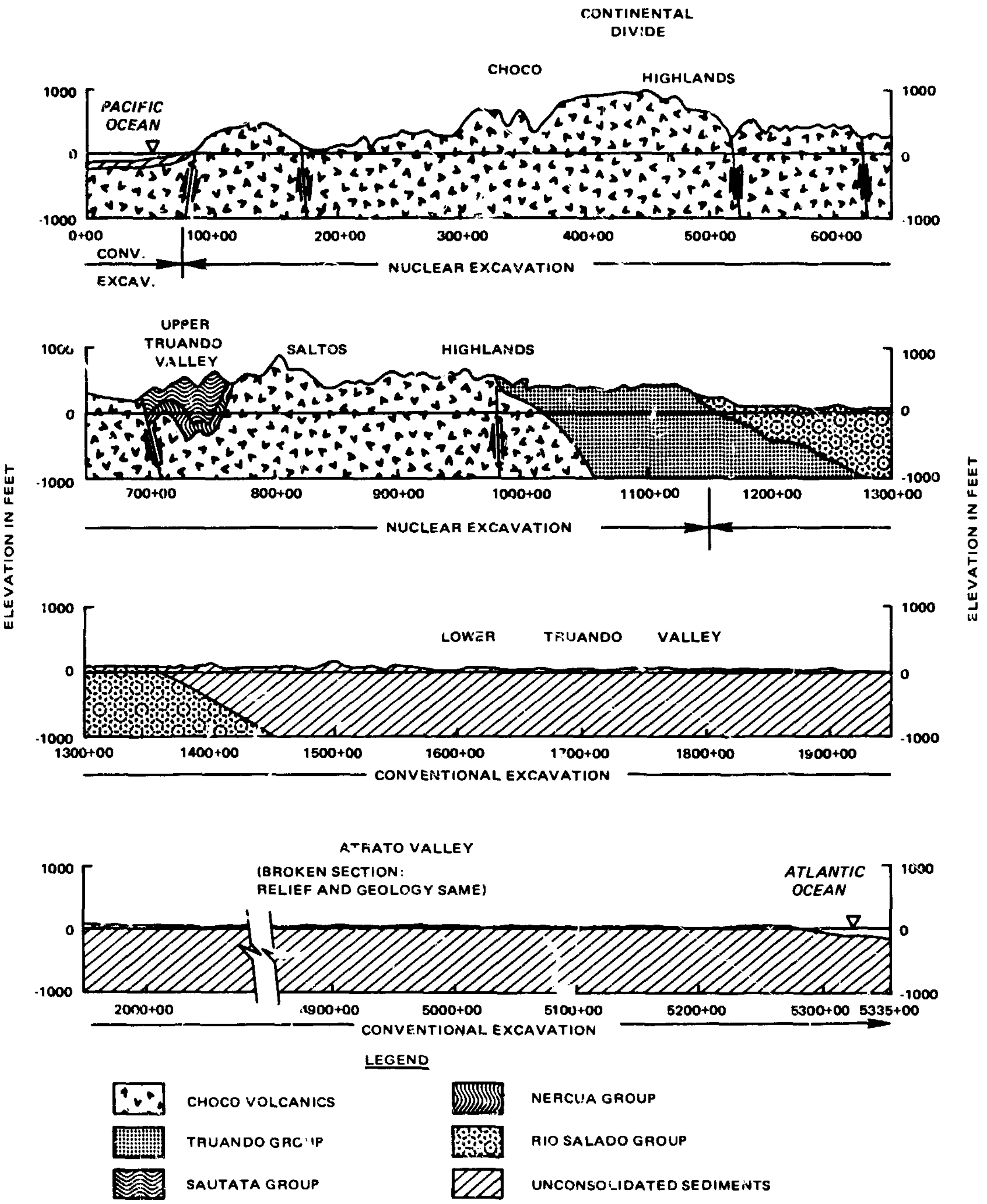
	Bypass Configuration	Two-Lane Configuration
Capacity at 20 hour TICW	Would exceed year 2040 transit requirements (60,000 transits per year) by almost 10%	Exceeds foreseeable requirement.
Time in canal waters	16 hours at 35,000 annual transits.	12 hours at 35,000 annual transits.
Navigation	Peak currents would rarely exceed 3 knots. Bypass operations would require careful control of vessels.	Capacity is so large ship spacing would present no problem.
Flexibility of operations	Some flexibility would be possible because of the high capacity. Highest currents could be avoided by occasional tight scheduling of large ships (less than one day per month).	Flexibility is virtually unlimited. Canal could be operated as two independent channels.
Expansion	Could be expanded to a du channel configuration at reasonable cost with little interference with traffic.	No foreseeable need.
Capacity at higher acceptable currents.	Not applicable	Not applicable.

[a]Based on the design channel in the conventionally excavated reach and a two-lane channel in the nuclear excavated reach. A 3-knot current is acceptable and no tidal check gates are used.

The dominant lithologic formation in the divide reach (between Stations 0 and 1000) is the Choco volcanics, consisting mainly of submarine basalt flows with some basaltic tuffs and agglomerates. These igneous rocks have been fractured and variably altered to produce substantial amounts of montmorillonite.* Some of the more altered zones slake upon wetting and drying, but on the whole, the Choco volcanics are considered suitable for nuclear excavation. In the upper Truando Valley, a 1- to 2-mile width of sediments, consisting of tuffaceous siltstones, sandstones and conglomerates, overlie the volcanics. A portion of these sediments, designated the Sautata group, is made up of a series of moderately hard siltstones and sandstones. The remainder of the valley is composed of Nercua conglomerate which is generally hard and dense but occasionally highly fractured. Crater slopes in both the Nercua and Sautata groups are expected to remain generally stable.

The transitional zone of sedimentary rocks of the Truando and Rio Salado groups lies between Stations 1000 and 1400. The Truando group consists of a series of tuffaceous siltstones, sandstones and mudstones, apparently capable of sustaining stable slopes in deep cuts, although limited testing indicated that some rocks in this zone are only marginally competent. The Rio Salado group is composed of soft claystone and mudstone having relatively low shear resistence.

*A clay mineral which expands readily on absorbing water, causing deterioration and weakening of the rock material in which it is found.



Geologic Profile
Route 25

FIGURE 22-2

The remainder of the alinement (between Stations 1400 and 5355) would lie in the Post-Miocene unconsolidated sediments of the Atrato flood plain. Elevations of the flood plain gradually decrease from about 16 feet above mean sea level on its southern edge to sea level at Candelaria Bay. Borings in the Atrato Swamp encountered layers of peat up to 20 feet thick, overlying silts and clays which extend to depths below channel grade.

Conventional excavation: A generalized excavation system for the conventional reaches of Route 25 is shown in Figure 22-3. Areas higher than elevation +75 feet along the Truando Valley portion of the alinement would be excavated by the shovel/truck haul system. Portions of the spoil would be used to construct flood control diversion works on the Truando River. At elevations below 75 feet hydraulic dredging would be the most economical excavation method. However, any material above 15 feet would be bulldozed or sluiced to within reach of 48-inch hydraulic cutterhead dredges. The dredges would work from sea level in pilot channels excavated from Candelaria Bay. Dredged materials would be placed on both sides of the canal behind retaining dikes constructed to confine the spoil. Spoil areas would be located at least 2,000 feet from the top of the final canal cut to permit expansion to two-lane configuration. Sufficient area is available to limit the average height of spoil behind the dikes to less than 6 feet.

In the ocean approaches project depth is reached within 3 miles of the shore of the Atlantic side and 2 miles on the Pacific. The Atlantic approach consists of sand and muck which would be excavated by hydraulic pipeline dredges. Soft materials in the Pacific approach would be excavated by hopper dredges, while rock would require blasting and excavation by barge-mounted draglines.

Volumes in the conventionally excavated portion of the canal, including a 28-mile bypass, are summarized below:

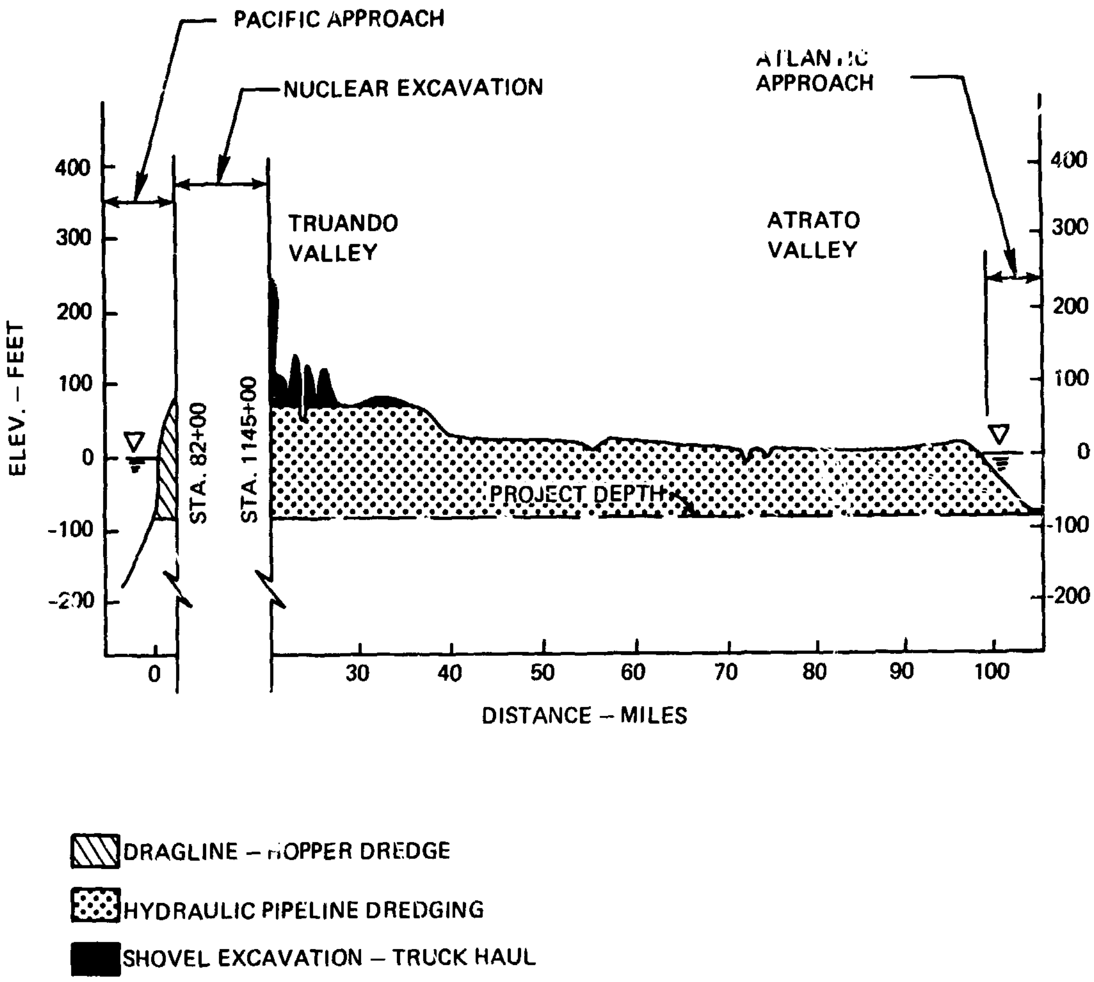
Conventional channel excavation summary

Type of material	Cubic yards	Percent
Common	1,500,000,000	88
Soft rock	195,000,000	11
Medium rock	–	0
Hard rock	15,000,000	1
	1,710,000,000	100

The total cost of conventional excavation would be approximately $700 million.

Spoil disposal areas: Undeveloped lands adjacent to Route 25 provide unlimited space for the disposal of this material. Most of it would be pumped through pipelines onto what is now a vast flood plain.

Nuclear excavation: Nuclear excavation would be carried out in two passes. The first pass (12 detonations) would excavate approximately one-half of the navigation channel and four flood control diversion cuts. The second pass would complete the navigation channel in



GENERALIZED CONVENTIONAL EXCAVATION METHOD
ROUTE 25

FIGURE 22-3

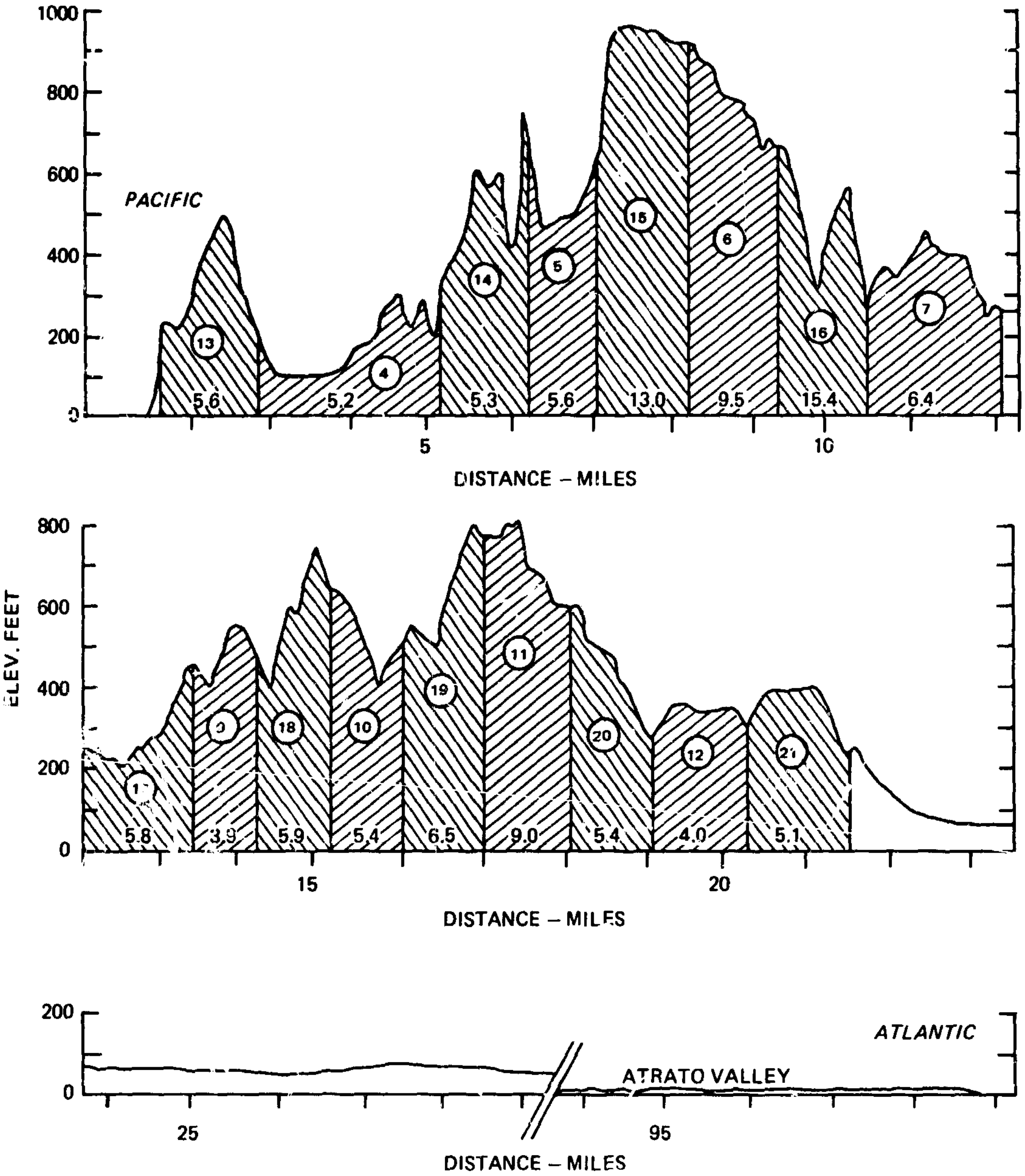
9 detonations by excavating connecting rows between the row craters formed by the first pass. The excavation program would require approximately 150 nuclear explosives ranging in yield between 100 and 3,000 kilotons. The largest detonation would have a total yield of 13 megatons.

The detonation sequence is illustrated by Figure 22-4. The order in which the sections would be excavated has been based primarily upon the need to minimize interference with preparations for succeeding detonations and follow-on conventional construction. Meteorological conditions should permit the first pass to be completed within 8 months. Following this, a period of about 21 months would be allowed for radioactive decay and emplacement drilling for the second pass. Then the intervening sections would be detonated over a period of 3 months. The cost of nuclear channel excavation is estimated to be about $185 million.

Stream diversion: As shown in Figure 22-5, the alinement would intersect the Atrato River near the town of Rio Sucio, about 50 miles upstream from its mouth. At this point, the Atrato (drainage area 12,000 square miles) would be diverted into Colombia Bay through a 1,000- by 50-foot dredged channel. This channel would be revetted to prevent the river from meandering into the canal. The 2,000-square mile watershed on the west side of the Atrato would be diverted through two floodways and portions of the abandoned Atrato channel to Candelaria Bay.

Diversion of the Truando River in the divide reach is infeasible because the river is deeply incised where it would be intersected by the canal alinement. A channel would be cut with nuclear explosives through the ejecta ridge along the canal to allow the Truando (drainage area 160 square miles) to flow directly into the canal. The Nercua and Salado Rivers (drainage area 125 square miles) would be diverted along the ejecta toe to discharge into the conventional reach of the canal. The Curiche River (drainage area of 21 square miles intercepted by the alinement) is the only stream of any size intersected by the canal on the Pacific side of the Continental Divide. It would be diverted through nuclear excavated drainage channels across three ridge lines to the Pacific. The total cost of the flood control facilities would be about $250 million, $230 million for conventional construction and $20 million for nuclear excavation.

Harbor facilities: Port facilities needed for canal operation and maintenance would not be as extensive as those now existing in the Canal Zone. Those ports are well developed and should serve as the principal regional ports, supplying various major services essential to shipping, such as repair and bunkering. Facilities for Route 25 are based solely on canal operational and maintenance needs; however, emergency ship repair facilities including mooring areas dredged to project depth have been included. Pacific port facilities would be located on the coast where they would be protected by a jetty system. Atlantic port facilities would be located near Sautata where the principal canal operating facilities would be established. Although this is about 30 miles inland, it is situated in an area offering better environmental conditions for a community than the deltaic regions near the coast. Anchorages in open-water areas of adequate depth would be provided outside each channel entrance. The general location of these facilities is shown in Figure 22-5. Their total cost is estimated at $129 million.

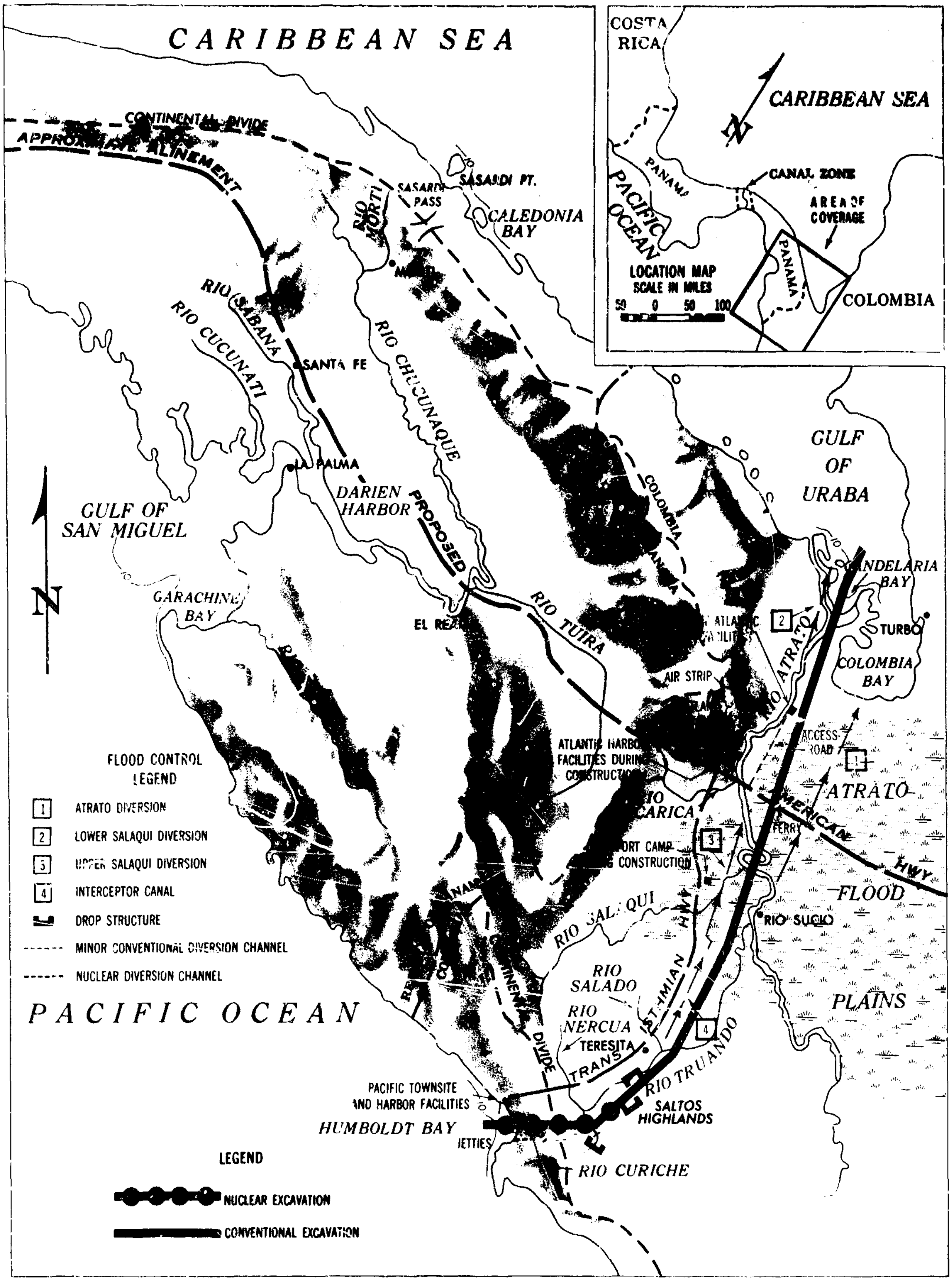


Note: Detonations 1, 2, 3, and 8 are for stream diversion cuts and are not shown.

(15) DETONATION NUMBER
5.0 DETONATION YIELD (MEGATONS)
1st PASS
2nd PASS

ROUTE 25 NUCLEAR DETONATION SEQUENCE

FIGURE 22-4



ROUTE 25 DIVERSION PLAN AND SUPPORT FACILITIES

PANAMA-COLOMBIA BORDER AREA

SCALE IN MILES

5 0 5 10 15 20 25 30 35

DEPTHS IN FATHOMS

FIGURE 22-5

Supporting construction: Items required to support construction are: health and sanitation facilities, housing, highways and bridges, clearing and relocations, channel cleanup, and operation and maintenance facilities. Their total cost would be approximately $431 million.

- **Health and sanitation**: The requirements for preventive medicine and medical support on Route 25 are similar to those on Route 10, except that their extent and cost would be larger because of the length of the canal, the undeveloped nature of the area and its distance from modern medical facilities.

  Medico-ecological investigations conducted as a part of this study showed a very high incidence of malaria among the natives of the area, including, on the Pacific side of the divide, a type *(falciparum)* which is resistant to chloroquine. For this reason, special effort would be directed toward the prevention of malaria. Disease vectors abound, particularly in the Atrato flood plain, and opening up the area by construction without proper preventive medicine measures could bring about an increase in diseases such as rabies, tuberculosis, arbovirus diseases (sleeping sickness), Chagas' disease (American trypanosomiasis), and leishmaniasis, which now exist there and in other parts of Colombia.

  An extensive medical support operation would be required from the very start of the project. A 50-bed hospital would be established at Sautata. It would be supported by existing facilities in the Canal Zone and would, in turn, support dispensaries at the Pacific terminus and the upper Truando Valley. The dispensaries and the hospital would support first aid stations established at the major construction sites, and would continue in operation, as needed, after completion of construction. Medical support would be designed especially to take care of construction accidents and tropical diseases, such as malaria and other parasitic diseases, enteric and skin infections, and related ailments.

  Both medical support and preventive medicine operations would be coordinated closely with Colombian, Panamanian, and Canal Zone authorities. They would also be closely coordinated with radiologic control. The cost of the medical support program would be about $44 million.

- **Housing and related support requirements**: Housing, utilities, and community services facilities would be provided to support construction and operating personnel. The alinement of Route 25 traverses an essentially undeveloped area, and few construction personnel could be recruited locally. Provision of adequate living facilities for the construction workers and their dependents would be an important factor in assuring an adequate labor force. During the construction phase, project personnel would be furnished housing comparable with that available at long-term construction projects in the United States. Permanent facilities would be built and used during both the construction and operating phases to minimize temporary construction. Figure 22-5 shows possible sites for such facilities. Their estimated cost is $182 million.

- **Highways and bridges**: A transisthmian highway consisting of an all-weather, two-lane highway from the Pacific end of the canal to Sautata would be provided. It would be one of the first items to be built and would serve both the construction

and operation phases of the canal. Secondary roads would lead to work sites along the canal. A ferry would be installed on the Pan American Highway where it crosses the alinement near Sautata. A permanent all-weather airfield suitable for supporting scheduled feeder airlines also would be provided. Figure 22-5 shows the proposed location for the principal permanent transportation facilities that would be provided as part of the project. Their cost is estimated to be about $67 million.

- **Clearing and relocations:** Clearing costs are included in the estimates for each construction item. Relocation costs would be insignificant.
- **Channel cleanup:** Fallback material within the nuclear excavated cut may encroach on the navigation channel, particularly at row crater connections. This material would be removed by barge-mounted draglines and dipper dredges and transported in the bottom-dump scows to be deposited in channel areas where cratering produced overdepth. This item also includes removing plugs at the ends of the nuclear reach by conventional excavation. This work would cost about $13 million.
- **Operation and maintenance facilities:** Facilities to operate and maintain the canal would be located at both of its ends, adjacent to the harbor facilities and townsites. These facilities would be similar to those provided for Route 10 and would cost approximately $129 million. Their location is shown in Figure 22-5.

Evacuation: Nuclear excavation would require evacuation of a large area adjacent to and downwind from the worksite. The exclusion area shown in Figure 18-3 has been developed to permit safe and efficient conduct of the nuclear excavation program. The area was made large enough to assure a high probability of containing almost all local fallout. Extensive observations showed that meteorological patterns would permit selection of detonation days in which all fallout would be toward the Pacific. The ranges of close-in airblast and ground motion effects were also considered. The nuclear exclusion area, roughly parabolic in shape, would comprise a land area of about 3,100 square miles in the Choco Department of Colombia, a region of very low population density, vast marshlands, tropical forest, and heavy rainfall. Because of its inaccessibility and ruggedness, less than 10 percent of the area has been cleared, inhabited or otherwise utilized, and only about 10,000 people live there. Navigation by small boat along the Atrato, Salaqui, and Truando Rivers provides the only means of surface access into the area.

The estimated cost of evacuating the exclusion area was based on the straight-fee indemnity system. Under this concept, all families or individuals would be paid an equitable price for their property which would enable them to resettle on available land outside the area. Since a safety exclusion period of several years would be required, a flat, one-time payment based on fair market value has been selected as a means of approximating safety evacuation costs. Indemnification of commercial enterprises in the area, such as lumbering and fishing, also is included in cost estimates. Relocation camps, temporary housing, and support facilities are not included but medical and other support services for the relocated local population would be provided, as needed, on an extension service basis by teams of specialists. The total project cost of real estate acquisition and limited support services for evacuees is estimated to be about $40 million.

Schedule: A schedule for designing and constructing the project is shown in Figure 22-6. It provides a minimum one-year design phase immediately preceding the start of construction. It assumes that work on such preparatory items as clearing, relocations, highways, and initial construction of townsites and power distribution systems can start immediately thereafter. Data collection would begin at the same time. After 2 years, emplacement construction for nuclear excavation would start. Four years would be required to complete this construction and subsequent nuclear operations. Conventional excavation would start at the beginning of the fourth year and continue for 10 years.

Personnel: Figure 22-6 also shows the requirements for personnel for design and construction of a canal along the Route 25 alinement. The length of Route 25 would dictate the need for more operating personnel than Routes 10 or 14S; about 5,000 would be required initially.

Cost summaries: The estimated cost of a 103-mile single-lane canal along Route 25 with one bypass is $2.1 billion, assuming that the 20-mile-long divide section could be excavated by nuclear methods. Principal elements of this total and their costs are:

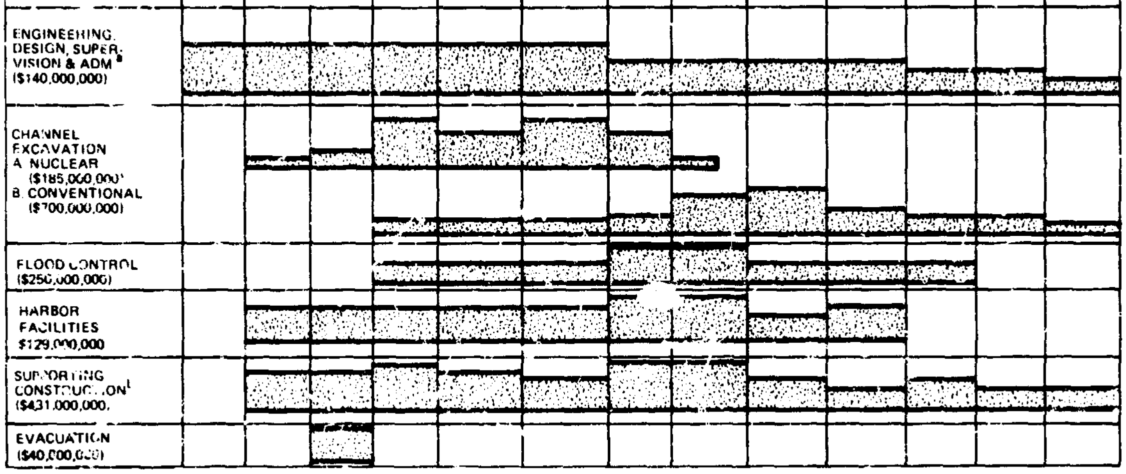
Channel excavation	
Conventional	$ 700,000,000
Nuclear	185,000,000
Flood control	
Conventional	230,000,000
Nuclear	20,000,000
Harbor facilities	129,000,000
Supporting construction	431,000,000
Evacuation	40,000,000
Subtotal	1,735,000,000
Contingencies	
Conventional (12%)	185,000,000
Nuclear (30%)	60,000,000
Subtotal	1,980,000,000
Engineering, design, supervision, and administration (7%)	140,000,000
TOTAL	$2,120,000,000

An estimated schedule of costs by year is shown on Figure 22-6.

Real estate: The cost for procuring land and easements along the canal for rights-of-way, flowage, and deposition of spoil has been estimated at $10 million, based on the market value of improvements and land use. This amount has not been included in project costs.

Environmental effects: Construction of the sea-level canal could be expected to cause significant local environmental changes, particularly in the Atrato River flood plain.

YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13
ANNUAL COST ($ MILLIONS)	14	86	150	244	212	194	218	288	253	158	121	108	74
CUMULATIVE COST ($ MIL)	14	100	250	494	706	900	1118	1406	1659	1817	1938	2046	2120
DESIGN AND CONSTRUCTION PERSONNEL	250	1240	2310	3640	3200	2890	3220	4480	3900	2530	1960	1510	1330
SUPPORT PERSONNEL	–	620	1570	1970	1880	1700	1880	2150	2030	1620	1140	1040	640
TOTAL PERSONNEL	250	1860	3880	5610	5080	4590	5100	6630	5930	4150	3100	2550	1970



[a] Width of bar shows relative amount of activity for each item.
[b] Includes area sanitation and health, townsites, highways and bridges, channel cleanup, and construction for operation and maintenance facilities.

ROUTE 25 COST PERSONNEL, AND CONSTRUCTION SCHEDULE

FIGURE 22-6

Excavation of the channel and construction of levees for spoil retention would modify the existing regimen of water elevations throughout a wide band along the route and increase saltwater intrusion. This band, like the rest of the valley, is now almost permanently flooded and covered by marsh grasses and shrubs. Large parts of the area would receive several feet of hydraulic fill which would raise them higher above sea level and provide conditions favorable to the growth of larger brush and trees. Under natural conditions this raised area could be expected to become tropical forest; it might also be put to economic use. The frequency, duration and depth of flooding over the remainder of the flood plain would not change significantly.

The ecology of the area surrounding the nuclear cut through the divide would be changed greatly, at least during the time required to re-establish the tropical forest. Compared to the extent of the whole region, the amount of land so affected would be small. Measurable radioactive fallout would extend over a much larger area but investigations made for this study indicate that no species as a whole would be significantly affected.

The effect of flow through an unobstructed sea-level canal has been discussed in connection with Route 10. The implications of this phenomenon on Route 25 are considerably less. The smaller tidal amplitude in Humboldt Bay and the length of the canal would serve to reduce the average net flow to less than 30,000 cubic feet per second. Water entering the canal at the Pacific would require several days before it could exit at the Atlantic. Thus Route 25 would provide a very poor passage for migrating biota.

The canal would cause a physical separation of the landmass, but no vital biotic migrations would be stopped. Access to the interior, now possible only along the Atrato River, would be improved by the diversion channels and by the transisthmian highway which would be built. The Pan American Highway, now under route survey, will also assist in opening the area to settlement.

Operation and maintenance costs: Operation and maintenance costs for Route 25 would be generally similar to those of Route 10, except that the much greater length of Route 25 would cause its costs to be considerably higher. The total operation and maintenance costs for 35,000 annual transits would be about $84 million per year.

Operation with the Panama Canal: The advantages of operating Route 25 in conjunction with the existing lock canal are similar to those of Route 10, although the substantial transit capacity of the bypass configuration makes it unlikely that the capacity of the Panama Canal would ever be required as a supplement. However, it would be advantageous to retain the Panama Canal in operable condition until the stability of sea-level canal slopes appears reasonably assured.

CHAPTER 23

SUMMARY ANALYSIS

Considered alone, construction costs do not provide a valid comparison between interoceanic canal alternatives. Numerous other factors merit consideration; however, many of them cannot be expressed in common terms so that they can be compared. In the analysis which follows, the factors which are considered to be within the engineering purview of route selections are discussed qualitatively and, to the extent possible, quantitatively. Some significant bases for comparison that are not included here are defense advantages, foreign policy benefits, and both foreign and domestic economic benefits. No attempt has been made to present a benefit/cost analysis.*

Route 10: In its basic single-lane configuration, Route 10 would have a transiting capability slightly greater than the Commission's initial capacity requirement (38,000 vs. 35,000 transits per year), even if operations were limited to currents not exceeding 2 knots. The design capacity of 35,000 transits per year could be attained with a TICW of about 12 hours. Acceptance of higher tidal current velocities would increase capacities substantially, with operations at 4 knots allowing 66,000 annual transits, 6,000 more than the requirement for the year 2040.

If current velocities greater than 2 knots were to prove unacceptable, transit capacity could be increased, if necessary, by the construction of a bypass, permitting 56,000 transits annually, closely approximating the year 2040 requirement. The capacity of Route 10 could be further expanded by enlarging it to a full 2 lanes.

Construction of Route 10 would provide a relatively short passageway between oceans, thus facilitating migrations of biota unless tidal checks are used. Other significant long-term ecological effects are not anticipated from this project, although there might be short-term disruptions from excavation and spoil disposal.

Route 14S: The basic single-lane configuration of Route 14S would cost about 6 percent more than Route 10 and would take 2 years longer to build. Its slightly greater capacity at 20 hours TICW does not appear to offset these disadvantages. At the initial 35,000 annual transit requirement, the average TICW would be about 10 hours. After the first logical expansion step of shortening the single-lane cut, the capacity of Route 14S at all current velocities would be about identical to that of the bypass configuration of Route 10.

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*Annex III, *Study of Canal Finance*, includes the effects on financial feasibility of variations in project initiation, time of construction, and interest rates.

Expansion to a two-way configuration, while meeting the requirements through year 2040, would produce less capacity in the two-lane configuration than Route 10. This difference is relevant only insofar as it relates to transit requirements beyond the year 2040. Of immediate and far greater significance is the fact that the Panama Canal could not be operated in conjunction with Route 14S because the lock canal would be rendered useless when the sea-level canal is put into operation.

In addition to environmental concerns similar to those associated with the construction of Route 10, excavation along Route 14S would draw down Gatun Lake and reduce its size. Although the adverse economic effects of a smaller lake would not be significant, the impact of its drawdown upon the environment and the general sanitation of the area could be severe.

Route 25: This partially-nuclear excavated canal with a bypass in its conventionally excavated reach could transit 65,000 ships per year, exceeding requirements for the year 2040. If nuclear excavation were feasible, this capacity probably could be developed at substantially lower construction costs than at either Route 10 or Route 14S. This canal could be expanded to a full 2-lane capacity at a much lower cost than either of the other two routes, with an ultimate capacity of 268,000 annual transits. The relatively large operation and maintenance costs of Route 25, resulting from its great length, would tend to offset its advantage of low initial cost.

Construction of Route 25 would convert a sizeable portion of the lower Atrato flood plain to land suitable for agriculture or forestry. Although such a conversion might have undesirable effects on the ecology of the Atrato's wetlands, these effects would be mitigated, at least in part, by the enhanced value of the raised land. The combined effect of a long canal and the potential for maintaining a biotic barrier with fresh water from the Atrato and Truando Rivers would act to limit successful interoceanic migration of biota. Adjacent to the divide cut, forests, surface drainage patterns, and wildlife would be seriously affected by nuclear ejecta but the climate should repair most vegetative and habitat damage quickly.

Sociologically, construction of Route 25 poses the problem of evacuating about 10,000 people from more than 3,000 square miles. Tentative relocation areas have been identified, but many of the evacuees would be Choco Indians, who might resist being moved to other unoccupied lands.

In any case, its dependence upon the use of nuclear explosives for the Divide cut causes serious consideration of Route 25 to be deferred until nuclear excavation feasibility has been established.

Route 15: The Deep Draft Lock Canal Plan would enable the Panama Canal's capacity to be expanded from 26,800 to 35,000 transits per year, and the size of the largest ship that it could accommodate would increase from the present 65,000 dwt to 150,000 dwt. The demonstrated ability of small ships to pass each other in the widened Gaillard Cut might allow as many as 40,000 transits per year, the estimated capacity of 3 lanes of locks. Operating costs would be relatively high and the attainment of ultimate capacity would depend in part on two lanes of old locks, whose remaining useful life is unknown. As is the case with Route 14S, the expanded lock canal would lack the flexibility of having another

usable canal available as an alternate or supplement. Expansion of the canal beyond the minimum configuration would be costly, and it is doubtful whether the capacity of 60,000 transits per year could be achieved with a fourth lane of locks; a capacity of 100,000 annual transits would probably require construction of another canal.

If economical methods to recycle lockage water cannot be developed, it would be necessary to pump sea water into Gatun Lake, which would increase the salt content of the lake sufficiently to affect its flora and fauna.

Environmental evaluation: The environmental implications of building a sea-level canal along the several alternative sea-level routes are summarized in Table 23-1. While Routes 10 and 14S are similar in many respects, Route 10 appears preferable, since it does not require the partial drainage of Gatun Lake. Its construction would not adversely affect the local culture, nor would it disturb any known archeological sites.

Design alternatives: Table 23-2 lists significant problem areas associated with the three principal sea-level alternatives; in effect, these areas represent costs – both quantifiable and unquantifiable. Table 23-3 summarizes the costs and transiting capabilities of the alternatives. These costs and capabilities can be influenced by certain modifications in design criteria. The following discussion considers a number of such possibilities and the effects they are likely to produce.

- **Use of a smaller prism**: The design channel was selected because of its ability to accommodate large ships safely in 4-knot currents. The use of tidal checks to reduce currents to 2 knots or less, implies that a channel smaller than the design channel might be used, with consequent savings in excavation cost. Figure 7-3 indicates that a 450- by 75-foot channel* would be satisfactory for 150,000-dwt ships transiting at a water speed of 9 knots and for 250,000-dwt ships transiting at a water speed of 7 knots. Nevertheless, despite the inclusion of tidal checks in conceptual designs and cost estimates, the design channel (550 by 75/85 feet) has been used throughout this study. The principal reasons for this practice are:
  - The design channel appears capable of accommodating many or all the ships in currents greater than two knots, without additional expense;
  - it would probably permit two-lane operations for many ships, thereby offering a means of increasing transit capacity without increasing construction cost;
  - it permits greater operational flexibility; and,
  - it provides for unforeseen contingencies in a field of technology that is not well understood.

*With a parabolic bottom having a centerline depth of 85 feet.

TABLE 23-1

SUMMARY OF SPECIFIC ENVIRONMENTAL IMPLICATIONS OF SEA-LEVEL CANAL ROUTES

Effects	Route 10	Route 14S	Route 25
Environmental conversions	A 36-mile strip of forested and semi-agricultural upland ecosystems would be altered to more complex ecosystems.	A 33-mile strip of upland ecosystem would be altered to more complex ecosystems.	A 20-mile strip of upland and 80-mile strip of wetland ecosystems would be altered to more complex ecosystems.
	Hydraulic and dry spoil would modify forest, lake and ocean areas.	Hydraulic and dry spoil would modify forest, lake and ocean areas.	Hydraulic spoil would modify extensive portions of the Atrato flood plain. Nuclear spoil would cover about 60 square miles of upland forests.
	Barrier dams across segments of Gatun Lake would reduce lake area and subdivide it into four separate small bodies of water.	Flood control dams across segments of Gatun Lake and the subsequent lowering of the lake level would reduce lake area and subdivide it into four small separate bodies of water.	---
	Diversion channels for Trinidad and Ciri Rivers and Caño Quebrado would alter two 5- to 10-mile segments of semi-agricultural land.	Gatun Lake dams would permit lowering lake level. 100 sq. mi. of lake will be converted to wetland.	---
Terrestrial effects	An additional barrier to overland migration would be created. Flora, fauna, and habitats would be eliminated by construction and spoil disposal.	An additional barrier to overland migration would be created. Flora, fauna and habitats would be eliminated by construction and spoil disposal.	An additional barrier to overland migration would be created. Flora, fauna, and habitats would be eliminated by construction and spoil disposal.
			Ejecta, airblast, ground shock, and radioactivity would affect wide areas near site of nuclear excavation.
			Possibility of physical danger and genetic alterations would exist.
Marine effects	Coastal waters at canal ends would be considerably altered. Migration of biota through the canal might result in establishment of undesirable species.	Coastal waters at canal ends would be considerably altered. Migration of biota through the canal might result in establishment of undesirable species.	Coastal waters and estuaries at canal ends would be considerably altered. Migration of biota through the canal might result in establishment of undesirable species.
	Breakwaters at Atlantic end of canal and Pacific jetty would modify environment.		Levee effect of spoil plus diversion channels will alter entire hydrology of flood plain with potential effects on entire estuary.
Freshwater effects	---	Some decrease in biotic populations would occur because of the reduction in area of Gatun Lake.	---
Unique effects	---	Swamp lands created by lowering of Gatun Lake may be undesirable.	Radionuclides may reach man through food chains and water supplies. About 10,000 people would be displaced.

TABLE 23-2

SIGNIFICANT PROBLEM AREAS*

	Route 10	Route 14S	Route 25
Physical characteristics of the site	Coastal protection is limited. Peak tidal currents in the canal could limit transit capacity unless controlled. Knowledge of divide geology is limited and very flat slopes might be required in some areas.	Peak tidal currents in the canal would be expected to limit transit capacity unless controlled. Divide cut region has known areas where flat slopes will be required.	Poor harbor potential and limited protection exist on the Pacific approach. Extensive river diversion would be required.
Environmental considerations	Net flow into the Atlantic would be relatively high unless controlled by tidal gates.	Gatun Lake area would be reduced by over 50 percent. Net flow into the Atlantic would be relatively high unless controlled by tidal gates.	A 3,100 square mile area, estimated to include about 10,000 people, would require evacuation for about four or more years. Radiation monitoring would be required for several additional years.
Construction	Weak materials in the divide reach present problems in designing stable slopes. Failure of the barrier dams is highly unlikely but could close the lock canal for up to 2 years and have a serious impact on new construction. Tidal checks are massive engineering structures which present special problems.	Weak materials in the divide reach present problems in designing stable slopes. Failure of the conversion plugs is highly unlikely but would have a serious effect on lock canal operations and new construction. Construction in and near the present canal alinement would involve a risk of slides and interference with lock canal operation. Construction barge traffic would present a hazard to canal shipping during several years in which traffic would be at or near capacity of the lock canal. Tidal checks are massive engineering structures which present special problems.	The feasibility of nuclear excavation must be established before construction could begin. Experience with megaton level row craters is lacking. Nuclear operations would be constrained by weather to prevent adverse fallout patterns and possible acoustic damage up to hundreds of miles from the site. Facilities required to support construction and operation would have to be provided.
Operation and expansion	Ship movements must be synchronized with operation of tidal checks. To achieve the year 2040 requirement at 2- and 3-knot current restrictions, a two-lane configuration would be needed unless the Panama Canal were kept in service and operated in conjunction with Route 10.	Ship movements must be synchronized with operation of tidal checks. To achieve year 2040 requirements at 2- and 3-knot current restrictions, a two-lane configuration would be needed. Construction of this route would eliminate the Panama Canal as a usable alternative or an expansion facility.	The configuration and capacity of this canal is based on the assumption that operation in a maximum current of 3 knots would be practical on this route.

*To the extent that these problem areas are quantifiable, they have been accounted for in estimating costs.

TABLE 23-3

DATA SUMMARY FOR OPTIONAL CONFIGURATIONS

I. MEETING MINIMUM REQUIREMENTS (35,000 transits/year)

	Route 10			Route 14S			Route 25[e]
Configuration	Single lane			Single lane			Single bypass
Construction cost	$2,880,000,000			$3,040,000,000			$2,100,000,000
Operation and maintenance cost	$57,000,000/year			$56,000,000/year			$84,000,000/year
Design and construction time	14 years			16 years			13 years
Current restriction[a]	2 knots	3 knots	4 knots	2 knots	3 knots	4 knots	3 knots[f]
Capacity (transits/year)[b]	38,000	45,000	66,000	39,000	42,000	59,000	65,000
Average TICW (at 35,000 transits/year)	12 hr	14 hr	12 hr	10 hr	15 hr	12 hr	16 hr
Average net flow (cu ft/sec)	neg.	4,000	33,000	neg	1,000	28,000	30,000

II. FIRST EXPANSION STEP CONSIDERED (60,000 transits/year target)

	Route 10			Route 14S			Route 25[e]
Configuration	Single bypass			Shortened restricted cut			Not required. Basic configuration permits 65,000 annual transits.
Additional construction cost	$460,000,000			$430,000,000			
Additional construction time	4 years			4 years			
Current restriction[a]	2 knots	3 knots	4 knots	2 knots	3 knots	4 knots	
Date required[c]	2001	2007	2040+	2002	2004	2025	
Capacity (transits/year)[b]	56,000	56,000	No gain	55,000	55,000	No gain	
Average TICW (at 60,000 transits/year)	d	d	38 hr	d	d	29 hr	
Average net flow (cu ft/sec)	neg	neg	13,000	neg	neg	13,000	

III. SECOND EXPANSION STEP CONSIDERED (100,000 transits/year target)

	Route 10			Route 14S			Route 25[e]
Configuration	Two lane			Two lane			Two lane
Additional construction cost	$1,520,000,000			$1,670,000,000			$630,000,000
Additional construction time	7 years			7 years			5 years
Current restriction[a]	2 knots	3 knots	4 knots	2 knots	3 knots	4 knots	3 knots[f]
Date required[c]	2017	2017	2018	2016	2016	2019	2040+
Capacity (transits/year)	114,000	114,000	195,000	82,000	82,000	113,000	268,000
Average TICW (at 100,000 transits/year)	6 hr	6 hr	5 hr	d	d	12 hr	12 hr
Average net flow (cut ft/sec)	neg.	1,000	50,000	neg.	neg.	50,000	60,000

[a]For safe navigation, currents are held at or below the value shown by use of tidal checks.

[b]Capacities are given for 20 hours average time in canal waters (TICW)

[c]Date when the requirement for transits would exceed the capacity of the preceding configuration when operating under the indicated current restriction. The transit requirement is taken from Annex IV, *Study of Interoceanic and Intercoastal Shipping*, for the "potential" tonnage projection, assuming 46% of the cargo is carried in freighters. This is the highest of the three predictions accepted by the Commission.

[d]Desired capacity cannot be obtained at any TICW.

[e]Because the application of nuclear excavation to this project has not been established, figures shown in this column are tentative.

[f]Operation of Route 25 with a two-knot restriction is feasible but not proposed. The physical characteristics of the route would prevent currents from exceeding about three knots.

Cost savings that might be realized by constructing the preferred routes with the smaller (450- by 75/85-foot) channel are:

	Route 10	Route 14S	Route 25
Estimated total costs with design channel	$2,880,000,000	$3,040,000,000	$2,100,000,000
Estimated total costs with 450- by 75/85-ft channel	$2,660,000,000	$2,800,000,000	$2,030,000,000
Estimated savings through smaller channel	$ 220,000,000 (7.6%)	$ 240,000,000 (7.9%)	$ 70,000,000 (3.3%)

– **Use of a 3-knot current limitation** A 2-knot current was selected as the limiting condition for navigation, although channel design was based on operating in 4-knot currents. The costs and capabilities of the routes have been compared on the basis of the 2-knot operating rule. A less conservative approach would be to hold currents on all routes to 3 knots, or less. This would increase transiting capacity and could lead to minor savings. Under those conditions, the gain in annual transits for the basic configuration of each route would be:

	Route 10	Route 14S	Route 25
Three knots	45,000	42,000	65,000
Two knots	38,000	39,000	–*
Gain	7,000	3,000	65,000*

At the first level of expansion (bypass on Route 10, extension of the two-lane channel on Route 14S) increasing limiting current velocities to 3 knots would produce no gain in capacity, although it would reduce TICW.

– **Possible increases in transiting speed**: Limiting currents to 2 knots in a channel designed for 4-knot currents implies that an operating speed of greater than 7 knots relative to land may be possible. Increased capacity would result if tidal gates were sited to take advantage of the higher land speeds for transiting ships. Possibilities in this regard are discussed in Appendix 6.

*With an average TICW of 20 hours, the capacity of Route 25 in the single bypass configuration would be extremely small if operations were limited to 2-knot tidal currents. Ships could transit only under favorable conditions. If a higher TICW of 24 hours were acceptable, the capacity would rise to about 40,000 annual transits. Alternatively, a dual bypass configuration with tidal checks would allow 45,000 transits at 21 hours average TICW with a 2-knot current limitation.

Although the adoption of any or all of these design alternatives could lead to minor changes in costs and capacities, the relative costs – both quantified and unquantified – and capacities of the several sea-level canal options would not be changed. Route 10 appears to be preferable under all conditions.

Sea-level/lock canal comparison: The fact that the Panama Canal already exists suggests incremental improvements in its capabilities, rather than its total replacement, as a means of meeting increased transiting requirements. Analyses made for this study show that the lock canal option preferred for meeting design criteria would be the Deep Draft Lock Canal Plan along Route 15, as discussed in Chapter 12. Table 23-4 compares the salient features of that plan with those of Route 10, the preferred sea-level canal alternative.

The principal advantages of Route 15 are its much lower initial cost for increased capacity and its low currents. Route 10 would offer better opportunities for expansion, either by raising the allowable operating current, by adding a bypass, or by using the capacity of the lock canal; it also would have lower maintenance costs.

Lock canal capacity is based on one-lane ("clear-cut") passage through the Gaillard Cut. If passing in the cut were possible for most ships, the capacity of Route 15 would approach 40,000 transits per year. Similar, but less, enhancement of capacity could be attained by allowing ships to pass in the design channel reaches of a sea-level canal.

Although enlargement of the Panama Canal would require the least capital outlay to meet minimum design requirements, its limited possibilities for subsequent expansion, its relatively high operation and maintenance costs, and the indeterminate life of its locks tend to offset this advantage of low construction cost. More significantly, the enlargement of the lock canal does not meet the Commission's stated requirements for transit. Hence, it is an unacceptable alternative.

TABLE 23-4

LOCK CANAL – SEA-LEVEL CANAL COMPARISON

Feature	Route 15 (Lock Canal)	Route 10 (Sea-Level Canal)
Initial cost	$1,530,000,000	$2,880,000,000
Time for design and construction	10 years	14 years
Capacity at 20 hours average time in canal waters	35,000 transits/year[a] 40,000 transits/year with passing possible in the Gaillard Cut for most ships	38,000 transits/year at 2-knot current 55,000 transits/year at 3-knot current 66,000 transits/year at 4-knot current
Maximum ship size	150,000 dwt, but not modern attack aircraft carriers	150,000 dwt 200,000 dwt in favorable currents
Operation and maintenance cost:		
Fixed	$51,000,000/year	$35,000,000/year
Variable	$580/transit	$840/transit
Environmental concern	Pumping salt water into Gatun Lake would make it brackish.	Transfer of marine biota between oceans would occur, with the extent depending on the amount of use of tidal checks. Spoil areas would be much more extensive than for Route 15.
Expansion possibilities	It is doubtful if the year 2040 requirement of 60,000 transits per year could be met with a fourth lane of locks.	A bypass section could be constructed for $460,000,000 and would provide a capacity of 56,000 transits/year at a 2-knot limiting current. Additional capacity would require raising the current limitation or providing a two-lane configuration. Use of the Panama Canal offers another means of expansion at least cost.
Operations	Careful navigation is required in entering locks, but currents would be no problem.	Convoy movements would require tight control to synchronize with operations of tidal checks. Currents may be a help to some ships; head currents may help some, tail currents may help others.
Maintenance	Scheduled lock maintenance would require periodic lane outages, thus limiting capacity temporarily.	Periodic tidal check gate maintenance would restrict operations but transit of smaller ships should be unaffected.
Miscellaneous	The existing 55-year old locks eventually may require replacement at an estimated cost of $800,000,000. The date of replacement cannot be predicted.	Route 10 could be used in conjunction with the Panama Canal, resulting in a system with a high degree of flexibility and dependability.

[a]Average TICW is 25 hours for Route 15.

PART V

PROJECT EXECUTION

Following a decision to build a sea-level canal, a number of issues would have to be resolved. They relate to:

- Management, funding, and organization of the project during both its construction and operational phases;
- Disposition of the Panama Canal; and,
- Further investigations which should be made prior to the initiation of construction.

CHAPTER 24

MANAGEMENT, ORGANIZATION AND FUNDING

The construction and operation of several large engineering projects were examined to discover those strengths and weaknesses which significantly influenced their effectiveness. These factors were analyzed to determine which would be relevant to a sea-level canal project. Such factors were translated into guidelines for future projects. The complete analysis is given in Appendix 4.

Construction: The construction projects considered are described briefly in Table 24-1.

TABLE 24-1

CONSTRUCTION PROJECTS EXAMINED

- **St. Lawrence Seaway:** Seven locks and connecting channels were constructed in a 5-year period through a 189-mile reach of the St. Lawrence River at a cost of $140 million, exclusive of power plants constructed by the State of New York. The St. Lawrence Seaway Development Corporation, established by Congress and the President of the United States, managed and directed the design, construction and operation of the United States portion of the seaway. The Corporation designated the Corps of Engineers to design and construct the locks and ship channel. Revenue bonds were used for financing. The United States cooperated with Canada on the project.[42]

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TABLE 24-1

CONSTRUCTION PROJECTS EXAMINED (Cont'd)

- **Tennessee Valley:** A 40,600-square mile watershed was developed for navigation, flood control, and generation of power. Twenty-six dams, 9 coal-fired power plants, and other facilities were constructed by the Tennessee Valley Authority, a government corporation. From 1933 to 1944 when the last major dam was completed, the project costs totalled $718 million. Funds were appropriated annually by Congress. The Authority was licensed to sell bonds for additional financing.[43]

- **Aswan High Dam:** This $1.12 billion project on the Nile River in Egypt is being constructed under the High Dam Committee which reports to the Ministry of Public Works, United Arab Republic. The main feature of the project, a rockfill dam, has a width of 1/2 mile at the base and a crest length of 2 1/2 miles. The Union of Soviet Socialist Republics has loaned funds for the construction of the project and requires the use of Soviet equipment. Total construction time will be about 12 years.[44]

- **Intercontinental Ballistic Missile Operational Bases:** More than 1,000 launch silos were constructed at 23 sites throughout the United States from 1958 to 1966 at a cost of $1.85 billion. The Corps of Engineers Ballistic Missile Construction Office (CEBMCO) acted as the design review and construction supervision agency under the U.S. Air Force which monitored the development, design and construction of the bases. Funds were appropriated by Congress.[45]

- **Snowy Mountain Scheme:** This project includes 15 dams, 100 miles of tunnels, 80 miles of aqueducts, and power stations with a total capacity of 3.8 million kilowatts. It was started in 1949 and at completion in 1974 will have cost almost $900 million. The Snowy Mountain Authority, an agency of the Australian government, is responsible for the construction, maintenance, management and control of the project.[4]

- **Taconite mines and processing plant:** An inland crushing and loading plant, a 47-mile railroad to Lake Superior, a pelletizing plant, a harbor, an ore loading facility, and towns for 4,000 employees were built between 1951 and 1955 at a cost of $187 million. The facilities were constructed by the Reserve Mining Company, jointly owned by ARMCO Steel and Republic Steel Corporation.[47]

- **The Panama Canal:** The 51-mile Isthmian lock canal involved over 5 million cubic yards of concrete and 280 million cubic yards of excavation. It was built between 1904 and 1914 at a cost of $275 million; defense facilities cost another $111 million. The planning, design and construction were supervised initially by an Isthmian Canal Commission of seven appointed by the President of the United States. Funds were appropriated by Congress. Rights to build the canal were granted to the United States by a treaty with the Government of Panama.[48]

TABLE 24-1

CONSTRUCTION PROJECTS EXAMINED (Cont'd)

- **The Suez Canal:** This 109-mile sea-level canal, involving 97 million cubic yards of excavation and connecting the Red and Mediterranean Seas was built between 1861 and 1839 at a cost of $189 million. A private company under Ferdinand de Lesseps managed and directed all funding and construction activities. The Government of Egypt agreed to permit the company to build the canal and to operate it for a period of 99 years.[48]
- **Missouri River development:** Five large dams along a 600-mile reach of the Missouri River involving about 200 million cubic yards of earthfill, [illegible] million yards of concrete and power plants with a capacity of 1.8 million kilowatts were built between 1947 and 1967 at a cost of $994 million. The Chief of Engineers, U.S. Army, delegated responsibility for design and construction to two Engineer Districts. Funds were appropriated annually by Congress.[49]

These projects were analyzed to determine their desirable and undesirable features, as might pertain to a sea-level canal. From this analysis, the following guidelines were derived:

- The project should be under the direction of an autonomous government authority empowered to seek funds as described below and to manage and direct all elements of planning, design, and construction. The authority should have no responsibilities other than those involved in building the sea-level canal. It should be governed by commissioners who work full time on the project and who would be expected to serve for the duration of the construction phase. The number of commissioners could be limited to three, including:
  - An individual highly qualified in corporate management involving construction.
  - An individual highly qualified in financial management of large projects.
  - A highly qualified engineer who would be designated chief engineer.
- The public law establishing the authority should be specific in defining the responsibility and functions of the authority.
- A satisfactory treaty should be negotiated with the host country prior to design and construction. The treaty should establish means for resolving routine problems associated with the construction effort.
- Funds for the total estimated cost of the project should be authorized by Congress concurrently with establishment of the authority. Project funds should be appropriated and allocated as required for orderly progress of the work. The authority should be empowered to issue revenue bonds for about ten percent of the estimated total project cost to supplement appropriated funds as necessary to assure orderly progress of work.
- Elements of one or more existing governmental agencies or departments having the requisite capability, experience and professional staff should be assigned and made responsible to the authority for designing the canal and its appurtenances, and contracting for and supervising its construction.
- Design and construction should be under the supervision and control of the chief engineer, who should be resident on site with his design staff. Construction should be accomplished on an area basis rather than a functional basis.

- Construction should be accomplished by contract. Contract duration should be made as long as practicable without penalizing contractors with the effects of inflation. Contract sizes should be varied to make best use of individual and joint contractors.
- To a limited extent, specialized equipment should be procured and owned by the authority and made available to contractors as needed, under rental agreements. All other plant should be furnished by the contractors.
- Division of direction and control of projects between the United States and the host country which would result in controversy and friction between the nations must be avoided.

Operation: Table 24-2 describes the projects analyzed to develop guidelines for operating the complete project. These guidelines are:*

- Management of operations at the sea-level canal should be accomplished by an independent government agency similar to the Panama Canal Company.
- Policy making authority should be vested in a Board of Directors, composed of representatives from industry, commerce and government. The Canal Director, a member of the Board, would be responsible for all elements of canal operations and would reside at the project. Supervisors responsible to the Canal Director would be in charge of operational elements such as traffic control, maintenance and engineering. Agency headquarters should be on site.
- The operating agency should not be formed by assuming the organization of the constructing agency and absorbing its personnel.
- The agency should have continuing authority to obtain funds from capital markets, as needed, for effective short-range and long-range planning, although specific authorization must be obtained from Congress prior to any issue of stocks or bonds.
- The agency should have a revolving fund upon which it could draw for minor capital improvements, operation and maintenance, and replacement of equipment. Funds for major capital improvement should be authorized and appropriated by item.
- Agreements with the host country on operational responsibilities and procedures must be made before construction begins. They should be specific and not subject to different interpretations which would adversely affect operation and maintenance.
- Maximum participation of the private economic sector of the host country in providing support services for shipping and operational personnel should be obtained.

*Guidelines concerning financial management are not included.

TABLE 24-2

OPERATIONAL PROJECTS EXAMINED

- **The Panama Canal:** This is a 51-mile-long (land cut plus ocean approaches) lock canal across the American Isthmus. In FY 1970 the canal transited 15,523 ships carrying 119 million tons of cargo. Average time spent in canal waters was 18 hours, of which transit time was about 7 hours.

- **The Suez Canal:** This 109-mile-long sea-level canal connects the Red Sea with the Mediterranean. In 1965, 20,300 ships transited the canal carrying 250 million tons of cargo, mostly petroleum. Transit time varied from 12 to 18 hours. The canal has been closed since 1967.

- **The Cape Cod Canal:** This is a sea-level canal 17 miles long (almost 8 miles is land cut) connecting Cape Cod Bay with Buzzards Bay in Massachusetts. Large boat traffic averages 6,000 transits annually carrying about 10 million tons of cargo. Small boat traffic averages an additional 12,000 transits annually. Transit through the land cut usually takes less than an hour.[50]

- **St. Lawrence System:** This lock canal system connects the Great Lakes with the Atlantic Ocean. The system includes the St. Lawrence Ship Channel, the St. Lawrence Seaway and the Welland Canal. Of these, the Welland Canal carries the most traffic, averaging more than 9,000 ships a year and 50 million tons of cargo, mostly bulk materials.

- **The Upper Mississippi River:** This includes a 9-foot navigation channel 663 miles long with 28 locks and dams. In 1968, cargo amounted to about 50 million tons. The system is closed during the winter.

CHAPTER 25

DISPOSITION OF THE PANAMA CANAL

Considering the long time required for design and construction of a sea-level canal, the on-going program of the Panama Canal Company to increase yearly transit capacity to 26,800 should be continued because it represents the most economical method of accommodating increased traffic for the next 20 to 30 years.

At the time of completion of a sea-level canal along any alinement except Route 14, the Panama Canal would retain its capability of transiting ships for a number of years, provided it is kept in operable condition. To make effective use of this capability would require that the two canals be considered as a single transiting system, even though the Panama Canal might not be in actual operation. As a part of this system, the lock canal might be operated at a low level of transits, be maintained on a standby status, or be placed in "mothballs". Ultimately, it might be dismantled or even abandoned.

Initial use: For a period of about ten years after the sea-level canal is opened to traffic, the Panama Canal should be kept as an emergency standby facility. During that period, most of the potential slope adjustments along the sea-level canal should occur, and if the adjustments were sufficiently large to interrupt traffic, the lock canal would be available to meet demands for transiting the isthmus. As assurance of slope stability is increased with time, maintenance dredging, without interrupting traffic, should be able to remove any slides that occur. Operating plans developed by this study call for maintaining the Panama Canal on standby for 10 years after opening of the sea-level canal.

Ultimate role: After that time the need to maintain the lock canal as a readily available emergency alternative might not warrant the expense involved, particularly if lock replacements became necessary. By then, operation of ships in the sea-level canal in currents greater than 2 knots should have been tested thoroughly. If such operation proved impossible, limiting the sea-level canal's capacity to about 38,000 transits per year, the lock canal would be needed to supplement the system's capacity until the sea-level canal is enlarged by the addition of a bypass or extension of the approach channels. The combination of unimproved sea-level and lock canals would be capable of accommodating more than 60,000 transits annually, with the sea-level canal transiting all ships larger than 65,000 dwt and both canals transiting smaller ships. Utilization of the system at this level probably would justify major maintenance expenditures for the lock canal.

If operation of most ships in currents up to 4 knots were to prove feasible, a one-way sea-level canal would meet traffic requirements past the year 2040, making dependence on the Panama Canal unnecessary. In that case, further maintenance of the lock canal would be of questionable value, and its salvage or abandonment should be considered.

If it appears that a full two-lane sea-level canal capacity is needed, conversion of the Panama Canal to sea level should be considered as an alternative to double-laning the sea-level canal.

The ultimate role of the Panama Canal cannot be determined at this time; and until the sea-level canal is a reality, no decision should be made which would preclude selection of the Panama Canal as the probable least expensive and quickest means of providing a larger number of additional transits if expansion of sea-level canal capacity becomes necessary.

Costs: The cost of operating and maintaining the Panama Canal is about $75 million per year for about 15,500 annual transits. A limited capability to respond to emergency requirements could be retained by operating the canal continuously at greatly reduced traffic levels. For example, instead of operating both of its lanes full time, a single lane could be operated on a one-shift basis, 5 days a week. This could be accomplished at an operation and maintenance cost of $4 million per year. It would serve to keep the lock canal machinery in working condition and would keep available at least one trained crew out of which to build a larger operating force quickly if the need arose. Compared to the operating costs of a sea-level canal, the cost of maintaining the lock canal appears insignificant; yet, the insurance it provides would be great.

Another method of maintaining the lock canal in operable condition would be to "mothball" it. This would cost an estimated $1 million initially; annual maintenance costs would be less than $1 million. These costs are relatively low but restoring the canal to operational status would take about a year and would cost about $5 million, including the cost of recruiting and training operating personnel. If reactivation could be phased over a period of several years, "mothballing" would offer an inexpensive means of maintaining the canal.

CHAPTER 26

FURTHER INVESTIGATIONS

Forecasts of transit requirements given in Annex IV, *Study of Interoceanic and Intercoastal Shipping*, show that the present canal, even after substantial improvements have been made, could reach its capacity as early as the year 1990.* Consequently, planning for construction of a sea-level canal should permit meeting that date. Estimates for Route 10 show a 14-year construction period, including a 2-year period of preconstruction engineering and design. To meet a 1990 opening date, a firm decision to proceed should be made no later than 1975, accompanied by a commitment of funds to permit detailed design to begin in 1976. Before these actions are taken, however, several specific aspects of engineering technology should be improved to permit design work to proceed expeditiously.

Investigations which should be undertaken to support eventual design of a sea-level canal fall into two general categories: those which expressly facilitate economic canal construction and those of much broader scope than the specific problems of an interoceanic canal project. In the first group are ecological studies to determine the risk of mixing the oceans; and subsurface geological investigations along the preferred route to assure the best siting for the canal and to increase the reliability of the slope designs. Those investigations which have a scope broader than canal construction include an analysis of existing clay shale slopes to improve design in certain large earthmoving projects, definitive investigations into the problems of navigating large ships in confined waters, and nuclear excavation, which should be pursued energetically to the point of establishing its feasibility.

Environment: The unanswered questions concerning the environmental impact of a sea-level canal center around the mixing of biota between the oceans. Recognizing the lack of agreement on this problem, the Commission asked the National Academy of Sciences to propose a program for further investigations in the event a canal is to be built.[39] The summary and recommendations of the National Academy report are shown in Inclosure E. In substance, the National Academy's program calls for further studies of:

- the commercial and sport fishing industries in the countries that might be affected by biotic interchange through the canal;
- the movement of water through the canal;
- the eventual disposition of excavation material;
- physical and biological oceanography in the Gulf of Panama and the Caribbean, including nearshore zone processes;

*This date is based on highest of the 3 transit projections accepted by the Commission. The other two accepted projections show that the capacity of the Panama Canal would be exceeded about the year 2000. Financial evaluation of the canal was based on these lower transit projections.

- dispersal and colonization processes;
- biotic barriers; and
- sampling and taxonomic analysis of inshore waters to a depth of 100 meters. This program would be accomplished by a separate commission established to conduct this work before, during, and after canal construction.

The Battelle Memorial Institute also proposed objectives for a marine ecological research program. Included among these is a mathematical simulation of critical components of the ocean mixing process to provide quantitative predictions of its ecological effects. Table 26-1 presents a comparison of data needed with those available to perform such model studies.

There are several qualified organizations which could undertake the recommended ecological studies, including the Smithsonian Institution which operates scientific centers in the Canal Zone.

Subsurface investigations: Excavation costs are governed by the type and quantity of material to be removed. In general, unit costs for excavating hard rock are higher than those for soft rock; however, hard rock can support steeper side slopes. Consequently, all other factors being equal, the volume of excavation through hard rock is considerably less than that through soft rock. Minimum excavation costs, then, are achieved by choosing that alinement which best balances unit costs – a function of the type of rock – and total volume – a function of the terrain elevations and the strength of the foundation material. Selecting the alinement which minimizes excavation costs would be possible only after extensive subsurface exploration. The cost of this exploration and accompanying analysis would be more than offset by possible savings in construction costs. The accomplishment of this work prior to the start of design is essential to the timely initiation and completion of the project.

Such a program is time consuming. It would require drilling closely spaced bore holes along and adjacent to the prospective route for geologic and soil analyses and boring several shafts for in place examinations. The program should be initiated in 1971 if optimum results are to be obtained by 1976. (See Table 26-2). Its costs would be about \$15 million, or \$3.0 million per year. Although experience indicates that, no matter how detailed design studies might be, some slides in a new canal would be inevitable because of adverse geological structures, every effort must be made to minimize their effects.

Conventional excavation of a test section: The slope criteria on which estimates in this study are based were derived largely from Panama Canal Company experience. The materials along Routes 10 and 14 are similar, but not identical, to those through which the present canal was excavated, but the slopes on the sea-level canal would be higher than those of the Panama Canal. Thus, criteria used in this study may not be suitable for all conditions to be encountered in building a new canal. A prototype section along the divide cut of the sea-level canal would provide the best means of improving and refining current slope criteria. But a suitable full-size test section with adequate length would be too large an excavation project* to undertake prior to commitment of substantial funds to the canal. Therefore,

*Estimated to cost approximately \$100 million for Route 10.

TABLE 26-1

COMPARISON OF PHYSICAL AND ECOLOGICAL DATA NEEDED AND DATA AVAILABLE FOR MATHEMATICAL MODELING OF MARINE MIXING

Data Needed	Data Available
Physical	
(1) Concentration profiles of limiting nutrients in the oceans at the termini and in the freshwater discharge into the canal	(1) Average concentrations of a few elements of radioecological importance, including some nutrient elements.
(2) Reaction rate constants for chemical reactions which produce or consume limiting nutrients	(2) Qualitative descriptions of a few typical reactions but no reaction rate constants
(3) Concentration profiles of salinity, suspended solids, and other materials characteristic of habitats near termini	(3) Scattered, uncertain concentration profiles for salinity and suspended solids, chiefly on the Pacific side
(4) Speed and direction of currents as a function of time (tide and season) nearshore, offshore, and in the canal	(4) Good estimates for average currents in the canal, scattered estimates of offshore currents in the oceans, no estimates of nearshore currents in the the oceans
(5) Measurements of turbulent diffusivities in the canal and in the oceans (e.g., by dye studies)	(5) Estimates of turbulent diffusivities from other localities
(6) Temperature profiles in the oceans and in the freshwater inputs to the canal	(6) Scattered temperature profiles in the oceans, none for freshwater
Ecological	
(1) Trophic structure of each ecosystem of interest	(1) Qualitative dietary information for numerous species, but no detailed information of trophic structure of any ecosystem considered
(2) Biomass of each trophic level	(2) Crude biomass estimates for phytoplankton, zooplankton, anchoveta, and shrimp in the Gulf of Panama
(3) Biomass and energy transfer rates between trophic levels	(3) Crude estimates of biomass transfer rates for above-listed groups in the Gulf of Panama
(4) Biomass, trophic level, and life history for each species of interest	(4) Crude estimates of phytoplankton biomass and productivity for one station in Caribbean and speculative estimates for crown-of-thorns starfish
(5) Biomass and energy transfer rates between species of interest and other trophic levels, predator-prey relations	(5) None except as metioned above
(6) Physiological tolerances of major species to principal environmental variables and effects of these variables on biomass transfer rates	(6) Gross speculations only

TABLE 26-2

SUBSURFACE INVESTIGATION PROGRAM (ROUTE 10)

Program for adjusting alinement		
Number of holes	184	
Total footage	73,600 linear feet	
Drilling cost	$2,160,000	
Downhole logging	200,000	
Laboratory testing	500,000	
Subtotal		$2,860,000
Program after alinement is firm		
Number of holes	1,450	
Total footage	193,000 linear feet	
Drilling cost	$5,800,000	
Downhole logging	700,000	
Laboratory testing	1,600,000	
Shafts and adits (7,200 LF)	2,160,000	
Subtotal		$10,260,000
Total program cost		
Total direct costs		$13,120,000
15% contingency		1,980,000
Total		$15,100,000

consideration was given to excavating a test section at the start of the excavation period. This, too, was found to be undesirable because it would require that a considerable portion of the total excavation effort be mobilized prematurely. Consequently, construction of a prototype section was dropped from further consideration as an item to be included in the predesign investigation program. Instead, the subsurface investigations program discussed above has been designed to provide requisite data relating to slope stability.

Clay shales and soft altered volcanic rocks· Neither the short nor the long-term stability of such materials as are found along the divide cuts on Routes 10 and 14 is well understood.

Consequently, conservative slope criteria have been used in preparing estimates for this study. Substantial savings might be realized if it were possible to construct the canal initially with slopes steeper than called for in this study. If necessary, slopes could be brought to their final configuration through maintenance after the canal has been put in operation. This would involve an element of risk. The study of clay shale slopes now being conducted by the Corps of Engineers and the Panama Canal Company should be augmented and carried forward to minimize the risk of using steeper slopes. The cost of this augmented program would average about $150,000 annually.

Navigation: The design channel used in this study is considered to be conservative in terms of its dimensions and the provisions it makes for tidal gates and tugs. Further analyses and model studies might point the way to safe navigation in a smaller channel, in faster currents or without reliance on tugs. A change in any of these factors could produce substantial savings in construction and operating costs. An investigative program costing about $300,000 per year for 5 years should either confirm navigational criteria used in this study or lead to better criteria for designing confined waterways. The investigations should combine the fields of tidal hydraulics, hydrodynamics of ship design, civil and marine engineering, mathematical and scale model simulation, ship handling procedures, and waterway management. The objectives of the program would be:

- To identify the relevant factors in the safe and economic design of confined waterways suitable for large ship navigation. This identification process should include a search and analysis of pertinent literature.
- To design processes for evaluating the relevant factors. If a simulation process is necessary, as appears likely, mathematical and scale model investigations should be planned in detail. These investigations should encompass information gained from the performance of ships in operating canals, with particular emphasis on pilot performance and its impact on the relationship between the ship and its behavior in a channel. Variable currents, current reduction methods, assistance from tugs and different methods of operating waterways should be considered in planning the evaluation processes.
- To perform the necessary evaluation processes.
- To analyze the results and prepare appropriate technical reports.
- To prepare a manual which would permit the design of the most economical safe channel in confined waters for large ships of specified sizes.

Nuclear excavation: Although nuclear excavation technology has not yet been fully established, it still offers prospects of substantial savings in large excavation projects. Investigations performed in connection with this study have highlighted what remains to be done to demonstrate the feasibility of this technique and the need to continue and intensify the joint nuclear excavation program of the Atomic Energy Commission and the Corps of Engineers. Its objectives should include those appropriate to nuclear excavation of the sea-level canal, as enumerated in Chapter 6. They should include a large-scale on-site cratering experiment. If for reasons not now foreseen, initiation of a sea-level canal is deferred, nuclear excavation, given sufficient impetus, might prove feasible for its construction.

Summary of further investigations: A program to investigate those problems which must be resolved prior to the initiation of detailed design is summarized in Table 26-3.

TABLE 26-3

PRE-DESIGN INVESTIGATING PROGRAM

Subprogram	Objective	Date*	Estimated Average Annual Cost
	Programs oriented toward a specific interoceanic canal route		
Ecological investigation	To conduct a continuing investigation into possible ecological consequences of constructing a canal, with emphasis on the mixing of marine biota.	1971 on	$ 2,000,000
Subsurface investigations	To determine enough detailed information about local rock characteristics to choose the optimum alinement and appraise material properties before detailed design begins.	1971-1975	$ 3,000,000
	Programs applicable to canal construction in general		
Slope stability investigations	To investigate the stability characteristics of clay shale and soft altered volcanic rocks to a point where the most economical sections through such material can be specified.	1971-1975	$ 150,000
Navigation of large ships in confined waters	To develop theory and data which will allow the design of the most economical navigation prism to meet specified requirements in large ship canals.	1971-1975	$ 300,000
Nuclear excavation technology	To develop the technology to the point where it can be demonstrated feasible or infeasible for constructing an interoceanic canal. The program should emphasize high-yield row detonations in saturated rock.	1971 on	$10,000,000

*Assuming initiation of design in 1975.

PART VI

CHAPTER 27

CONCLUSIONS

Concerning the engineering feasibility of a sea-level canal:

- Construction of an interoceanic sea-level canal is feasible now.
- The feasibility of employing nuclear excavation techniques for this purpose has not yet been established; consequently, if excavation of the canal were undertaken within the next several years, it would have to be by conventional means.
- No ecological factors have been identified which would preclude construction of a sea-level canal; however, a number of possible environmental problems should receive further study if it is decided to proceed with this project.

Concerning the best alternative for meeting projected traffic demands:

- The best present means of meeting the initial requirement for a capacity of about 35,000 annual transits for ships with maximum size of 150,000 to 250,000 dwt is a conventionally-excavated sea-level canal along Route 10.
  - That canal should consist of a single channel 550 feet wide at a depth of 75 feet below mean sea level at its edges, with a parabolic bottom 10 feet deeper along its centerline. Provision should be made for tidal gates until the feasibility of operating the canal with unregulated flow is demonstrated.
  - The Panama Canal should be retained as a supplemental facility and operated, as needed, in conjunction with Route 10 as a single system.
  - A canal built along Route 14 Separate having the characteristics described above would meet the initial requirement at approximately the same cost as Route 10. However, Route 14 is less desirable because it entails some risk of prolonged interruption to Panama Canal traffic, its adverse environmental impact is greater than that of Route 10, its construction eliminates the Panama Canal as a supplemental facility, and its expansion capabilities are more limited than those of Route 10.
- Determination of the best means to achieve additional capacity should be deferred until the sea-level canal has been in operation for several years. Alternatives considered at that time might include:
  - Relaxation of the conservative operating procedures that are contemplated in this study.
  - Construction of a bypass or lengthening of two-lane reaches in the sea-level canal.
  - Increased utilization of the Panama Canal, including construction of additional locks.
  - Conversion of the Panama Canal to provide a second sea-level canal.
  - Construction of a second sea-level canal by nuclear means.

Concerning the use of nuclear excavation:

- If the decision to build a sea-level canal is deferred, the use of nuclear explosives for its excavation should be reconsidered.

Concerning construction of a sea-level canal:

- Construction of a sea-level canal along the Route 10 alinement would take about 14 years, including 2 years for preconstruction planning and design.
- Total construction costs for this canal are estimated at about $2.88 billion.
- These estimates should be updated when authorization of construction is sought.

Concerning organization of the construction effort:

- Construction should be controlled and directed by a commission reporting directly to the President.
- All funds required for construction should be budgeted and justified by the commission which should have supplemental independent financing authority as necessary to assure uninterrupted progress of the work.
- The commission's organization in the field should be drawn from existing federal construction agencies but should be made responsible only to the commission.
- Design and supervision of construction should be performed by the field organization, with sufficient authority delegated to its chief to enable him to carry out his responsibilities effectively.
- To the fullest extent possible, construction should be carried out under contract; items of equipment which by their nature or size are peculiar to this project should be Government-owned and made available to the contractors.
- The commission and its field organization should be dissolved upon completion of construction.

Concerning the operation of a sea-level canal:

- The sea-level canal and the Panama Canal should be operated as a single system under an independent Government agency or Government-owned corporation.
- The operating agency should have limited financing authority to provide for maintenance and necessary improvements.

Concerning increasing Panama Canal capacity in lieu of constructing a sea-level canal:

- It is not practicable to meet the Commission's stated transiting requirements through major improvements of the Panama Canal.

Concerning actions to be taken now, unless the decision to build a sea-level canal is to be deferred at least 10 years:

- Specific studies of the effects of a sea-level canal upon regional ecology should be undertaken immediately.
- An extensive subsurface exploratory program should be conducted along the route selected to determine the precise alinement of the canal before detailed design begins. The Corps of Engineers, working in coordination with the Panama Canal Company, appears to be most appropriate for this task.

Concerning actions to be taken now, regardless of when the decision is made to build a sea-level canal:

- The modernization program of the Panama Canal Company to expand the capacity of its existing facilities to 26,800 annual transits should be pursued vigorously.
- Nuclear excavation technology should be developed to the point where its feasibility will be known by those who must make decisions on canal construction. To that end, the joint Atomic Energy Commission – Corps of Engineers nuclear excavation research program should receive continuing support.
- The dynamics of ships moving through confined waterways should be fully determined. The Corps of Engineers, in consultation with the Department of the Navy and the Maritime Administration, should formulate and execute a program to develop basic understanding of this subject.
- Stability of high slopes in clay shales and soft altered volcanic rocks should be investigated to the point where safe and economical slopes in such materials can be designed. The Corps of Engineers, operating in coordination with the Panama Canal Company, should continue its work toward that objective.

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TECHNICAL ASSOCIATES FOR GEOLOGY, SLOPE STABILITY AND FOUNDATIONS OF THE ATLANTIC-PACIFIC INTEROCEANIC CANAL STUDY COMMISSION

CONSULTING GEOLOGISTS	CONSULTING ENGINEERS
FRANK A. NICKELL – San Mateo, Calif.	ARTHUR CASAGRANDE – Cambridge, Mass.
ROGER RHOADES – San Francisco, Calif.	PHILIP C. RUTLEDGE – New York, N.Y.
THOMAS F. THOMPSON – Reno, Nevada	

March 2, 1970

Mr. Robert B. Anderson, Chairman
Atlantic-Pacific Interoceanic Canal Study Commission
726 Jackson Place, N.W.
Washington, D.C. 20506

RE: COMPARISONS OF INTEROCEANIC CANAL ROUTES

Dear Mr. Chairman:

The scope and organization of the following report result from discussions during the meeting with Commissioners Hill and Fields in San Francisco on January 28 and 29, 1970. It consists of two main sections, one concerned with Routes 17 and 25 that require nuclear excavation and the other with Routes 10, 14C and 14S that would be constructed wholly by conventional excavation. The concepts and conclusions have evolved from association with the investigation since its beginning in 1965 and from continuous review of the extensive investigations and reports of the Corps of Engineers' study groups. Detailed technical recommendations, which were reported to the Corps of Engineers periodically during the study, are not repeated herein.

The comparisons between routes have been based on considerations of geology and engineering related to design and construction of a canal, in light of the existing state of knowledge of effects on slope stability, to result in an evaluation of the relative merits, disadvantages, uncertainties and risks of routes for a sea-level interoceanic canal. In the first main section Routes 17 and 25 are compared assuming feasibility of nuclear excavation and the feasibility assumption is then considered. In the second section comparisons of conventional excavation routes are made between Route 10 and Routes 14C and 14S and then between the latter two routes within the Canal Zone.

ROUTES REQUIRING NUCLEAR EXCAVATION OVER PORTIONS OF THEIR LENGTH

Routes 17 and 25 require nuclear excavation of very deep cuts through the mountainous sections to make them economically feasible. These routes are first compared in their entirety and then the feasibility of nuclear excavation for canal construction is discussed. Assuming that nuclear excavation is feasible, comparison of Routes 17 and 25 logically divides itself into the mountainous sections requiring nuclear excavation, the lower-lying sections excavated by conventional methods, and requirements for diversion of flood waters.

(1) Mountainous Sections

The continental divide on Route 17 is near the Atlantic side and is near the Pacific on Route 25. The highest elevations are roughly the same but the length of high elevation for Route 25 is somewhat less. The geology and basic types of rocks are similar and will permit relatively steep excavation slopes such as might be produced by nuclear blasting.

On Route 25 it seems possible for reasons of geology that nuclear excavation could be extended farther to the east than shown on the construction plan, thereby reducing the requirement for more costly conventional excavation.

On Route 17 there is a second high ground section near the Pacific entrance. This presents two distinct disadvantages; first, the geologic structure of the Pacific highland is more complicated than in the continental divide and the rocks are less competent, creating some uncertainty as to stability of slopes produced by nuclear excavation; and second, the two separated sections requiring nuclear excavation doubles the number of interfaces with conventional excavation sections. Such interfaces and transition zones between the two types of excavation introduce uncertainties into design and construction. Design problems include: (1) the selection of the points where the transition can safely be made, and (2) determination of stable slopes for the transitions. Construction problems exist in extending conventional excavation into the deep masses of broken rock created by larger nuclear explosions.

In balance, the problems of nuclear excavation are less on Route 25 and this route is the more favorable for nuclear construction if and when feasibility of the method can be established.

(2) Conventional Excavation Sections

Route 17 includes a length of about twenty miles across the Chucunaque Valley where the average ground surface is about Elev. 200. The underlying rocks are clay shales of the Sabana beds in which the possibility of creating stable slopes by nuclear excavation procedures is very unlikely. In fact, proper slopes for conventional excavation would have to be developed for these weak rocks and some trial excavations would be required to establish economical safe slopes. In addition, it is not yet known how far the weaker rocks of formations bordering the Sabana Beds extend into the foothills of the Atlantic and Pacific

divide sections but geologically it seems possible that conventional excavation might have to extend into relatively high ground, further increasing difficulties and costs.

In comparison Route 25 has a length of eighty miles across the Atrato Swamps but the surface elevation for most of this length is close to sea level. Generally, the materials for the full depth of the canal prism are soft organic deposits and unconsolidated soils which can be removed by hydraulic dredging. Techniques for building a canal in such materials are well established, no unprecedented methods are required, and no significant difficulties are anticipated. It would also be easy to widen or to divide the canal into separate channels in this section if sufficient space is left between protective levees in the initial planning.

In summary, the greater length of conventional excavation on Route 25 is more than offset by absence of grave uncertainties in design and construction as compared with Route 17.

(3) Flood Diversion Requirements

Route 25 has the disadvantage of large volume rivers with heavy silt loads flowing toward the alignment in its lower reaches. These flows would create unacceptable conditions in the sea-level canal; large and long flood diversion channels are required on both sides of the canal to carry the flood waters to safe discharge into the Atlantic, particularly on the east side where the flood channel for the Atrato River approaches the size of the canal itself. The penalty lies in volume of required excavation and cost, but no particular design and construction difficulties are anticipated.

Head water river flows on Route 25 will enter the canal but the volumes of flow are small and no particular difficulties are anticipated. On Route 17 it is planned to drop the flows of the Sabana and Chucunaque Rivers into the canal. The flood flows here are somewhat larger than the head water river flows into Route 25 and the silt load is expected definitely to be larger, creating a requirement for maintenance dredging in the Route 17 channel. No particular difficulties are anticipated in developing a design for safe dissipation of energy where the waters of these rivers are dropped into the canal.

Feasibility of Nuclear Excavation

Feasibility of excavation by nuclear explosions is discussed in terms of: (1) the present situation, i.e., the possibility of its being used with assurance for interoceanic canal construction within the next ten years; (2) the requirements for a continuing program of nuclear testing to assure future feasibility; and (3) the possibilities of future applicability to weak rocks such as the clay shales of the Chucunaque Valley. These discussions apply exclusively to the physical development and configuration of craters which would result in a usable canal and exclude all other effects of nuclear explosions such as seismic, air blast, and radiological hazards.

(1) Present Feasibility

The Technical Associates are in unanimous agreement that the techniques for nuclear excavation of an interoceanic canal cannot be developed for any construction that would be planned to begin within the next ten years.

The reasons for this opinion are:

a. Extension of the scaling relations now established by tests to the much higher yield explosions is too indefinite for assured design and the "enhancement" effects due to saturated rocks and row charge effects now assumed have not been proved by large scale tests.

   There is a definite possibility of a major change in the mechanics and shape of the crater formed by the much higher yield explosions required for the canal excavations as compared to extrapolations from the relatively small-scale tests carried out to date.

b. The effects of the strength of rock on the stability of "fall-back" slopes and the broken rock crater slopes projecting above the fall-back to the great heights required for an interoceanic canal have not yet been established.

   Therefore, the Technical Associates conclude that nuclear excavation cannot safely be considered as a technique for assured construction of an interoceanic canal in the near future.

(2) **Future Development**

The economic advantages of nuclear explosions for excavation of the very deep cuts required by an interoceanic canal are so great that the present "Plowshare" program should be continued, extended, and pursued vigorously until definitive answers are obtained. Assured application of this technology to design and construction of an interoceanic canal will require an orderly progression of tests up to full prototype size, including full-scale row charge tests, in generally comparable rock types, terrain and environment. Such a program may well require another ten to twenty years to establish whether or not nuclear excavation technology can be used with positive assurance of success for construction of a canal along Routes 17 or 25.

(3) **Application to Excavation in Clay Shales**

A growing body of knowledge and experience indicates that high slopes in clay shales, as in the Chucunaque Valley, or in more competent rocks underlaid by clay shales, as in parts of the existing canal, may have to be very flat for long-term stability and to avoid the danger of massive slides in the first few years after excavation. Some attempts have been made to produce such flat slopes by elaborate explosive techniques, such as over-excavation in anticipation of slides, multiple row charges, and successive series of explosions or "nibbling" techniques for application to problems such as construction of a sea-level canal across the Chucunaque Valley. The Technical Associates believe this to be a highly unpromising line of investigation with minimal chances of developing procedures that could be used with assurance in the foreseeable future.

ROUTES CONSTRUCTED BY CONVENTIONAL EXCAVATION

Routes which would be constructed wholly by conventional methods are Route 10 about ten miles to the west of the existing canal and generally outside of the Canal Zone

and Routes 14 Combined and 14 Separate both in the Canal Zone and near the existing canal. The relative advantages, disadvantages, risks and uncertainties will be discussed first as between Route 10 and either of the Routes 14 and second as between Route 14C and Route 14S.

Experiences with slides in the excavated slopes of the existing canal near the continental divide clearly demonstrate that achieving reasonably permanent slope stability is a major problem and would be a large economic factor in the design and construction on any of these routes. Comparisons herein are based primarily on uncertainties and risks of instability of excavated slopes, with some attention to the stability of structures and excavation spoil placed on top of the soft Atlantic mucks of the Gatun Lake area. All comparisons relate to the alignments and excavation slopes presented in the final reports prepared by the Corps of Engineers' study groups operating under the supervision of the Engineering Agent. It is recognized that some of the risks discussed herein have been partially compensated for by adoption of different slope design criteria for the three routes, as earlier recommended by the Technical Associates. The following discussion pertains to remaining advantages, disadvantages, uncertainties and risks.

Comparison of Route 10 with Routes 14C and 14S

Route 10 has the following advantages: (a) it could be constructed and placed in operation without hazard to or interferences with the existing lock canal which could be maintained on a standby basis. A slide during construction or in the first few years of operation, while undesirable, would not result in complete blockage of trans-isthmus ship passages as it would on Route 14C or 14S. (b) A large part of Gatun Lake could be maintained permanently at its present elevation by barrier dams, which would not be particularly difficult to construct where Route 10 crosses the lake. (c) By virtue of its separation from the existing canal and Gatun Lake, a large part of the excavation could be accomplished in the dry by well-established construction methods. (d) Large portions of the tremendous volume of excavation spoil could be transported to the Pacific and Atlantic Oceans for useful construction of breakwaters and for disposal with the least effect on the environment. (e) The terrain lends itself well to economical construction of a ship by-pass channel near the middle third of the length, if increases in traffic should make this necessary. This is not possible on Route 14.

A major disadvantage and uncertainty of Route 10 along the alignment presently explored is that about eight miles of the length across the continental divide, the highest and largest excavation volume part of the route, appears to be underlain by soft altered volcanic rocks at depths which would have major unfavorable effects on stability of excavation slopes. There is no precedent of excavation experience for the slope stability characteristics of these soft altered volcanics but results of laboratory testing indicate that they may be at least as weak as the clay shales which have caused severe slope instability along the existing canal. Thus, relatively flat excavation slopes have had to be assumed, even when adopting an "observational approach" in which trial slopes would be excavated and observed as full-scale tests to determine the steepest safe slopes.

The critical geology and structure of the underlying formations on Route 10 is completely masked by a thick basalt capping across the divide area. It must be assumed,

however, that similar structures and faulting as along the existing canal underlie the basalt. Some geologic evidence indicates that lateral shifting of the alignment of the reach through the continental divide, perhaps by a mile or so, might encounter more competent underlying rocks. If so, the disadvantage of higher terrain might be more than compensated for by use of steeper slopes, thereby reducing both excavation volumes and uncertainties. Therefore, design studies for Route 10 should include explorations of offset alignments in search of the best rock and geologic structure. This will require a very large number of core holes to depict the geologic conditions adequately for reasonable design and will necessitate one or more years' lead time for accomplishment of these required investigations. It is the geological consensus, however, that design explorations will not disclose subsurface conditions that are worse than those along the line now explored and which are reflected in use of conservative soft rock slopes for the entire eight mile length.

Routes 14C and 14S have the advantages of more extensive and complete subsurface and surface geological explorations in the area of the existing canal and of smaller excavation volumes due to the generally lower topography. An exception is the crossing of Gatun Lake at its widest point where barrier dams to establish differences in water levels may require large excavations and massive quantities of fill. Their disadvantages are almost certain interferences with operations of the existing canal during construction, complete loss of the existing canal during and after conversion to a sea-level canal, and loss of Gatun Lake in its present form. There are also uncertainties and risks of major slides which are discussed more fully in the comparison between Routes 14C and 14S.

Comparison of Route 14C with Route 14S

(1) Slope Stability

In the continental divide section Route 14C involves hazards of major slides which could close the existing canal for long periods of time during construction of the new canal, and which thereafter could block the sea-level canal. These hazards result from much deeper excavations through sections where landslides have already been activated by construction of the existing canal. They would be particularly serious during the period of rapid drawdown required for conversion to a sea-level canal. While allowances for this hazard have been made in recommendations for slope design, there still remain unknowns and uncertainties concerning the effects of the rapid drawdown (in a period of about ten days) on the stability of slopes where past sliding and stress readjustment have created major planes of weakness.

Gold Hill presents a particular hazard to Route 14C. Observational records indicate that this rock mass is moving erratically and is squeezing softer materials below its base upward into the existing canal. It is believed that safe construction of Route 14C would require unloading of Gold Hill which will significantly increase the volume of excavation.

By virtue of its separation through the critical divide cut length, the hazard of slides blocking the existing canal are much less for Route 14S. It is possible that its excavation could still endanger the stability of Gold Hill but both the hazard and magnitude of any corrective unloading would be greatly reduced.

(2) **Excavation and Excavation Spoil**

Due to its location contiguous to the existing canal, Route 14C requires underwater excavation of large volumes of rock, excavation to depths greater than 150 feet below the operating water surface by construction procedures which are without precedent. In addition, a large part of the divide cut excavation spoil would have to be hauled to disposal in Gatun Lake which would drastically change the configuration of the residual lake. In contrast, practically all of the divide cut excavation for Route 14S could be made in the dry by methods for which there is ample precedent and a large part of the excavation spoil could be disposed of in the Pacific.

Excavation spoil deposited in Gatun Lake, whether it be in the form of barrier dams or non-functional waste areas, will rest on the soft Atlantic muck deposits forming the lake bottom. Stability studies for barrier dams in the central portion of the lake have shown that these weak materials create major dangers of massive slides during the rapid drawdown of the lake to sea level, which is certainly required on the canal side of any spoil piles. Thus, regardless of the intended purpose of the spoil piles, very flat side slopes and all of the protective measures incorporated in the design of barrier dams will be required wherever the spoil is not confined by existing rock islands. This condition applies equally to Routes 14C and 14S although, for the latter, the volumes of spoil in the lake could be greatly reduced.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the considerations summarized in the preceding sections, the Technical Associates for Geology, Slope Stability and Foundations have reached the following conclusions and recommendations:

1. The physical feasibility of excavation of a sea-level canal by nuclear explosions is not now established. Therefore, nuclear excavation cannot be recommended for consideration for any canal that should enter construction within the next ten years. However, if design and construction of a new interoceanic canal are to be deferred one or more decades, nuclear excavation techniques hold promise of such great economic advantages that investigational and testing programs, as recommended in this report, should be pursued vigorously, but with the following exception. Attempts to excavate stable slopes in deep cuts in clay shale rocks by explosive procedures are so unlikely to produce acceptable or safe result that further investigations or tests in this direction are not recommended.
2. Assuming that nuclear excavation is now a feasible assured construction technique and in terms of the technical uncertainties and risks then remaining, the choice between Routes 17 and 25 is decisively in favor of Route 25 in spite of its greater length.
3. For routes constructed by conventional excavation the advantage of Route 10 being separated from the existing canal far outweighs potential difficulties and uncertainties in comparison with Routes 14C and 14S. If this route is selected, the Technical Associates recommend that the existing canal be maintained in an operational condition for at least ten years after a new separate canal has been placed in operation. By having the existing canal available in the event of a

temporary blockage of the new canal, Route 10 would justify economies which are inherent in an observational approach to the selection of design slopes, but which involve some risk of slides after completion of construction.

4. If for reasons not considered herein a route within the Canal Zone is considered imperative, construction of Route 14S introduces substantially fewer hazards and uncertainties than Route 14C. Route 14C would result in filling large portions of the Gatun Lake area with excavation spoil, which is not necessary for Route 14S, and has substantially increased hazards of canal blocking slides caused by the drawdown of water levels accompanying conversion to a sea-level canal. Major geologic surprises are not anticipated on these routes.
5. A valid comparison cannot be made between Routes 10, 14C and 14S, all of which would be excavated entirely by conventional means, and Routes 17 and 25, both of which require nuclear excavation for the planned construction. Nuclear excavation is not yet a proven construction technique and there is no assurance that construction plans and cost estimates based on present knowledge are valid. Therefore, dollar cost comparisons at this time have no true significance. The comparisons presented herein between Routes 17 and 25 are based on the assumption that assured feasibility of nuclear excavation can be developed by tests over the next decade or two, at which time construction on Route 25 might be planned with some confidence. If earlier construction of a sea-level canal should be recommended by the Commission, it is urged that the route selection be restricted to Routes 10 and 14S which can be constructed by presently known techniques of design and excavation.

The Technical Associates for Geology, Slope Stability and Foundations hope that this report, based solely on technical considerations of risks, uncertainties and favorable aspects of the several routes considered for a sea-level canal, will be of assistance to the Commission in its final deliberations and recommendations.

Respectfully submitted:

Arthur Casagrande

Arthur Casagrande, Consulting Engineer

Frank A. Nickell

Frank A. Nickell, Consulting Geologist

Roger Rhoades

Roger Rhoades, Consulting Geologist

Philip C. Rutledge

Philip C. Rutledge, Consulting Engineer

Thomas F. Thompson

Thomas F. Thompson, Consulting Geologist

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BOARD OF CONSULTANTS ON CONVENTIONAL EARTHWORK CONSTRUCTION METHODS OF THE ATLANTIC-PACIFIC INTEROCEANIC CANAL STUDIES

L. Garland Everist
Western Contracting Corporation

J. Donovan Jacobs
Jacobs Associates

Grant P. Gordon
Guy F. Atkinson Company

Lyman D. Wilbur
Morrison-Knudsen Company, Inc.

July 9, 1970

General R.H. Groves, Engineering Agent
Atlantic-Pacific Interoceanic Canal Study Commission
Office of the Chief of Engineers
Washington, D.C. 20315

Dear General Groves:

The Board of Consultants on Conventional Earthwork Construction Methods was organized in the latter part of 1966. It visited the Panama Canal Zone in October 1966 and has met on six subsequent occasions, the last being in July of 1970. All meetings except the last were arranged by the Jacksonville District of the Corps of Engineers of the United States Army with presentations by the Corps of the status of studies to date and proposed method of attack to arrive at the best solution to date. At each meeting the Board was asked a number of questions that were answered in writing. During discussions at each meeting the Board was asked to criticize freely the work that had been accomplished by the Corps since the previous meeting. The Board did so, as well as offer suggestions as to methods, production, equipment systems and type of management and construction organization. Since the Corps' report reflects most of the Board's suggestions and comments, we will not try to repeat them here. However, it may be of interest and useful for the Board to make the following observations with reference to the studies:

1. **PRESENT SCOPE OF INVESTIGATIONS.** The studies on conventional excavation methods prepared by the Commission have been made in an excellent manner and result in sound conclusions using the data presently available. It appears that all reasonable alternates have been considered and properly weighed in an effort to arrive at the best solutions of construction systems and costs. Since it will be some

time before construction will actually begin, new information and factors will no doubt cause some changes in methods and estimates. We believe that the estimates are adequate to compare the various alternates and properly evaluate their relative merits and determine the probable actual cost.

2. **CONTINGENCY FACTORS.** We have found that the Corps has been most anxious to get the best thinking possible into their studies. They have welcomed our suggestions and modified their estimates to conform to our ideas with one exception and that is an item of contingency. Most contractors in estimating a project of the magnitude of the proposed sea-level canal take into account the uncertainties of effect of weather, production, support items left out of the estimate, and other factors by making their best estimate of cost and then adding a contingency factor of from 5 to 10% in addition to their expected profit. We believe that the 6% included in the estimates for contractor's profit should be increased by another 5 to 10% to cover the construction contingency. This is not to be confused with the usual engineer's contingency of 5 to 10% to cover changes in quantities or design. The contractor's profit usually does not exceed 6% but the extra costs represented by the contingency item do occur.

   This addition to cost is not important in making comparisons for route selection, as all costs would be adjusted proportionately. Also this increment of cost will no doubt be overshadowed by the effects of escalation, and changes in available equipment before the project is actually constructed. This item should be considered as indicative of the range of accuracy of the estimates. In making authorizations and appropriations, it should be taken into account.

3. **EFFECT OF SLOPE CHANGES AFTER START OF CONSTRUCTION.** It is recognized that it is uneconomical to excavate side slopes to an absolutely safe slope that would eliminate all slides. It has been suggested that an experimental section of the canal be excavated to assist in determining the best slopes for the balance of the excavation. Because of the high cost of such an experiment, the time involved and the effect of its interference with the overall construction scheme, the Board believes it to be more desirable to spend efforts on drilling to obtain more subsurface information on which to base the design of side slopes.

   The slopes should then be designed reasonably safe based on the best practice and interpretation of subsurface exploration and the experience on the present canal. After construction starts the slopes can be changed as the work progresses if found necessary. It must be recognized that the cost of flattening the slopes will be considerably greater per unit of quantity than the original excavation.

4. **FEASIBILITY.** The proposed interoceanic canal will be the largest earthmoving operation ever attempted. Nevertheless construction on any of the routes can be accomplished with conventional equipment and within a construction period of 10 to 14 years. Because of the large numbers of giant-sized equipment units needed, two years will be required to mobilize for the major excavation effort. Because of the much greater quantities of excavation on Routes 17 and 25, the cost will greatly exceed the cost for Routes 10 and 14 unless nuclear excavation is proved feasible.

Although improved construction equipment and methods will tend to reduce costs, it can be expected that the increasing wage and price spiral will more than offset equipment advances so that excavation costs will increase during the next decade.

5. **EQUIPMENT SYSTEMS USED.** The equipment systems used in the estimates are all well established and have proven out in actual practice on many of the construction jobs and mining operations being performed today. The principal difference between present operations and those proposed for the interoceanic canal is the magnitude of the job and the requirement to assemble in one place and at one time the largest fleet of jumbo-sized equipment ever attempted to date. No two construction projects are ever exactly the same so that it is impossible to base estimates on actual overall costs on previous jobs. However, the various elements in a job have usually occurred previously on some other work so that the elements can be combined to represent the overall conditions expected on the project under consideration. This has been the approach for the interoceanic canal studies.

   In an area of high rainfall the effect of weather must be taken into account. A barge or waterborne equipment system is the least affected by rainfall. Systems involving rail operations are affected less than systems relying on trucking, which is the most adversely affected in areas of high rainfall.

   Use of barrier dams to permit excavation of the Gatun Lake portions of Route 14 has been considered. However, the final estimates have been based on deep dredging with suction dredges, draglines and dipper dredges without the use of barrier dams. Although the depth of dredging required has only recently been successfully accomplished with suction dredges, the Board anticipates no serious problems in using this method in Gatun Lake. The Board believes the problems involved using this method will be less than with barrier dams.

   The cost estimates have taken into account the weather factor by utilizing a truck-oriented system to excavate only in the higher elevations where rail or barge transportation is the most costly. Comparative estimates have been made for both barge and rail-oriented systems for various parts of each route with the least costly system being adopted as the project estimate. Suction dredging for the Atlantic and Pacific approaches rounds out the four systems used in the cost estimates for the various parts of conventionally excavated routes. The Board concurs in this selection as being most appropriate for arriving at the soundest cost estimates based on present technology.

6. **OTHER EQUIPMENT SYSTEMS.** The wheel excavator with transportation by conveyor belt has been adapted to large scale excavation in recent years. Under suitable conditions, this is an ideal system but unfortunately the conditions of weather and material along the various canal routes do not appear to fit this system.

   The front end loader is rapidly replacing power shovels for excavating and loading hauling equipment. It may be that by the time construction on the interoceanic canal starts that this tool would be further developed so that it would replace some of the power shovels now contemplated. However, it is unlikely that the cost estimates would be greatly affected by such a change.

Self-propelled scrapers are an effective tool for excavating and moving equipment medium distances. It is probable that some of the excavation estimated for shovel and trucks will actually be accomplished with scrapers. However, the effect on overall costs will be negligible.

Some of the excavation in the medium hard rocks has been estimated using barge mounted draglines and shovels (dipper dredges). Some of this excavation could be handled by suction dredge but the Board believes this method would not result in any reduction in cost.

7. **PREFERABLE ROUTES FOR INTEROCEANIC CANAL.** Of the five routes (10, 14C, 14S, 17 and 25) considered by the Board, Route 10 is the most preferable from a conventional construction standpoint. Access and interference with other installations or activities are important considerations. None of the routes present any obstacle that cannot be met and overcome by the competent constructor. However, Routes 17 and 25 are in remote areas and will require more effort to provide support facilities as nothing is presently available, thus requiring the building of 100% of the support. This will take time as well as money and would delay start of construction on the canal. Also the local labor supply is negligible as compared to Routes 10 and 14C or 14S. The adverse effect on these two routes can be measured by the cost involved. Route 10 is more remote than either 14C or 14S and would require some additional support facilities, such as roads. However, it is close enough to the existing Canal Zone, Panama City and Colon, so that the housing, personnel, utilities and other facilities now available to the existing canal could be utilized to the fullest extent. Some additional transportation of personnel would be required for Route 10 as compared to Route 14 (about 10 miles per day). This would also involve another quarter hour of time for personnel living in existing facilities to be away from home. This is not considered a serious matter but might add a little to cost of labor.

The principal advantages in Route 10 over Routes 14 are two-fold; (1) that it is sufficiently remote from the existing canal to remove the restrictions that would be required for blasting and waterborne traffic on Routes 14, and (2) that it permits a wider choice of equipment systems. Route 14C requires the most wet excavation with waterborne equipment. Route 14S requires less wet excavation but much more than for Route 10, where all excavation except the Atlantic and Pacific approaches could be in the dry. Alternatively, practically all of Route 10 could be accomplished by barge haul if that ultimately was determined to be the cheapest.

In the Board's review of the cost of conventional excavation portions of Routes 17 and 25, we did not give any consideration to the additional cost of excavating through the large masses of broken rock that would have to be excavated where the conventional excavated canal connects to the nuclear excavated canal. The costs of this excavation might greatly exceed that of non-disturbed material. Although allowances have been made in the estimates for the extra cost of excavating this broken material, there is no past experience that gives a firm basis for being assured of the costs involved.

8. **ORGANIZATION AND MANAGEMENT OF THE CONSTRUCTION EFFORT.** To manage the construction of the canal, a new Government agency, not bound by

tradition and present rules, should be established, drawing on personnel from the Corps of Engineers, Naval Facilities Engineering Command, Bureau of Reclamation, and outside sources.

The canal should be constructed by competitive unit price contracts, with provisions covering escalation of costs and advance payment for equipment. By proper advance planning, this can result in the use of the most efficient equipment system.

In order to take advantage of the ingenuity of American contractors, the equipment required for the job should be purchased and owned by the contractors with advance payments being made to cover its cost, transportation and installation. While some advantages would accrue in standardization if the Government were to buy and own the equipment, this gain would be more than offset by the loss in efficiency in a contractor being required to utilize equipment that was not suitable to the job as units that he might devise or procure.

9. **TYPE OF CONTRACT.** Because of the size of the contracts and the overall time for constructing the project, it will be necessary to provide unusual features in the contracts. Most contractors hesitate to enter into fixed price contracts that will extend for more than a period of four or five years. The construction period for the interoceanic canal will last 10 to 14 years in addition to the two years required for equipment procurement. The objection to long term fixed price contracts may be alleviated by providing for escalation of labor and material costs and/or by providing for renegotiation at the end of five or six years. One type of contract that we believe would be suitable to the construction industry would provide for

(a) operations during the entire equipment procurement and construction period;

(b) firm prices for a four-year period from date of contract (although escalation from start of construction would reduce the contingency and might lower costs);

(c) payment for equipment, freight and erection as costs are incurred by the contractor;

(d) escalation payments to cover 90% of increased costs of labor, materials and supplies after the first four years of the contract.

Another type of contract could require firm prices for a fixed period, after which the contract would be renegotiated on the basis of proven increases in cost due to escalation and possibly other factors. If a price satisfactory to all parties could not be negotiated, the Government agency would take over the contractor's equipment on a predetermined basis and re-advertise for the completion of the work.

For any type of contract the Government agency in charge should require the bidder to list in detail the major items of plant, equipment and plan of operation to be used with the requirement that there be no changes unless such changes are approved by the agency. The agency should reserve the right to award the contract to other than the low bidder if it is not satisfied with the system proposed by the low bidder. Prequalification of bidders should be considered.

10. **CONTRACT PACKAGES AND THEIR SIZE:** Construction of housing, roads, utilities, power supply, docks and other support facilities should be let by separate

contract at as early a date as possible after it is decided to proceed with construction of the canal. These contract awards should be followed as soon as possible by the letting of the major earthwork contracts so as to allow for as much time as possible to procure plant and equipment.

In order to give the smaller contractors a chance to obtain a portion of the work, the shovel and truck operations planned for the upper levels in the Continental Divide section of the canal should be broken down into the smallest sizes that the agency believes can be effectively administered. (The size of these packages would be in the $5-20 million range.) However, a number of these smaller packages should be let at the same time with the bidders being given an opportunity to tie together any number of the packages they may want to accept, if by so doing the price is lower than would be the case if the packages were let separately. Presumably most, if not all, of the smaller contracts would be for a relatively short construction period and it might not be necessary to provide for escalation or renegotiation.

Dredging might be let in small individual packages but in order to attain the lowest costs any small packages should be bid simultaneously so that bidders could tie together as much as they would want to accept in order to give the best price.

In order to take advantage of large equipment the major part of the work, presently scheduled to be accomplished by shovel and rail or shovel, dragline and barge haul, must be let in as large packages as is possible without eliminating the desirable competition. Although not many contractors are able to bid on jobs in the $100-400 million range, recent years have seen contractors forming joint ventures to bid on jobs in excess of $400,000,000 (Tarbella Dam). The Board believes that there would be adequate competition if the work packages were kept under $500 million (1970 dollars). This is particularly true if the contractor is relieved of the financial burden of the plant and equipment as recommended herein. If the design of the canal involves required fill as well as excavation, the fill must be tied to the excavation from which it will come, in a single package.

11. **ADVANCE PLANNING, AUTHORIZATION AND APPROPRIATIONS.** Advance planning will require appropriations of funds before construction funds are required. These should be made available at an early date.

Before construction starts, the Congress should give assurance that appropriations will be made in sufficient amount and over a sufficient period of time so as to permit construction of the canal by the use of the most efficient equipment systems and economical contractual arrangements.

The estimates of cost above referred to are predicated on adequate financing to meet the requirement of the work program. Delay in the planning sequence will develop an inordinate increase in costs.

We recommend that during the precontractual stage the planning agency convene at least three nationwide conferences of contractors, equipment suppliers, and other interested parties for the purpose of familiarizing them with the project and its problems. The conferences spaced six months or more apart should be carefully organized and skillfully conducted over a period of two days or more.

The Board of Consultants on Conventional Earthwork Construction Methods trusts that this report will be of assistance in the determination of the route and construction

management of the Interoceanic Canal. Representatives of the Construction Industry welcome the opportunity of participating in the development of projects such as the interoceanic canal as it gives an opportunity to present its views and thereby assist the Government in arriving at the best solution to its problem. A wealth of construction knowledge and experience is available for the asking. The Board considers it a privilege to have been given an opportunity to express its views to the Commission.

Respectfully submitted:

L. Garland Everist

Grant P. Gordon

J. Donovan Jacobs

Lyman D. Wilbur

ROUTE 15 ENVIRONMENTAL IMPLICATIONS STATEMENT

Environmental Statement Pursuant to National Environmental Policy Act of 1969 (P.L. 91-190), Section 102(2) (C) for Modification of Panama Lock Canal.

Project description: The plan for modernization and expansion of the Panama lock canal is designed to improve upon the capability of the present facility by increasing capacity, updating operations and maintenance characteristics and reducing its vulnerability to military attack or sabotage. The need for such improvements is indicated by the limitations of the present canal. In 1970 there were approximately 1,300 ships afloat, under construction or on order which could not pass through the existing locks under any conditions. Approximately 1,700 others could not pass through fully laden. An even more serious limitation is that part of the route is above sea level, and a considerable volume of water is required for the operation of the locks needed to raise and lower the ships during passage. The steady increase in transits, now over 15,000 per year, points out the need for providing more lockage water. Recycling lockage water or pumping seawater must begin within the next several years, undoubtedly before a sea-level canal would be built. As the demand increases, the average transit time will also increase, causing expensive delays. Projections of the postwar demand rate indicate that the number of ships desiring to use the canal would exceed 19,000 per year before the year 2000.

The Panama Canal runs generally in a northwesterly direction from Balboa on the Pacific coast to Cristobal on the Atlantic. The Miraflores Locks, a double-lift twin-lock structure which raises vessels 54 feet from the level of the Pacific Ocean to Miraflores Lake, are about 6 miles inland from the Pacific. Pedro Miguel Locks, a single-lift twin-lock structure at the other end of this 1-mile-long lake, raises vessels to Gatun Lake at elevation 85 feet. From these locks the canal passes directly into Gaillard Cut, which extends for 8 miles through the Continental Divide. From the cut's north end near Gamboa, the canal follows a 23-mile irregular course through Gatun Lake to avoid islands and peninsulas. At the north end of the lake are the Gatun Locks, triple-lift twin-locks which lower vessels to sea level about 2 miles inland from Limon Bay. The total length of the Panama Canal, including approaches, is 48 miles. The 12 lock chambers are 1,000 feet long, 110 feet wide and have limiting depths of 40 feet over the sills. The minimum navigation prism is 500 feet wide by 42 feet deep, with about 3 additional feet of overdepth. The existing facilities will accommodate ships up to about 65,000 dwt.

The plan developed for an improved lock canal incorporates the most desirable features of previously proposed lock canal plans. Provision was made for transiting 150,000-dwt ships and flatter excavation slopes were assumed than those of earlier designs. This plan calls for adding a lane of triple-lift locks to the existing 2 lanes at Gatun, and constructing a separate lane of triple-lift locks at Miraflores to raise 150,000-dwt ships into a bypass

around Pedro Miguel at the level of Gatun Lake. It has the advantage of permitting continued operation of all existing locks throughout their useful lives and could accommodate 35,000 transits per year. When the existing locks could no longer be used economically their replacement could be accomplished with minimum interference to traffic and would consolidate all three lifts on the Pacific side at Miraflores, raising Miraflores Lake to the level of Gatun Lake.

An improved lock canal would have the inherent handicap of requiring extremely large quantities of lockage water. This requirement can be met by pumping ocean water into Gatun Lake, or possibly by recirculating fresh water. The first method would render Gatun Lake brackish, thus changing some ecological characteristics of the area, while the second would involve unusual engineering problems. Both methods would entail costly pumping operations.

Construction would interfere with traffic through the Gaillard Cut, Miraflores Lake, and Pedro Miguel and Miraflores Locks.

The construction effort involved would be about evenly divided between lock construction and channel excavation. The new locks would take advantage of the Third Locks excavations made in 1940-1942. Excavation would be accomplished mainly by dipper dredges and spoil would be removed in scows. Construction would take about 10 years and cost about $1.5 billion. Additional costs would be incurred when the existing locks require replacement.

The authority for this study was established by P.L. 88-609 on 22 September 1964, with a basic charge to create a Commission to investigate, study and determine a site for the construction of a sea-level canal connecting the Atlantic and Pacific Oceans. The date of the Commission's report to the President, as amended by P.L. 90-359 on 22 June 1968, is 1 December 1970.

The environmental setting without the project: The narrowest part of the American Isthmus lies in and adjacent to the existing Panama lock canal. It is also the area of lowest topography. The isthmus at this point runs nearly east and west and at its narrowest point is about 40 miles in width (between Limon Bay on the Atlantic and the Gulf of Panama on the Pacific). The Continental Divide roughly parallels the Pacific coast, about 10 miles inland. Local hills in the divide in this area rise to about elevation 1,200 feet. A secondary divide at a lower elevation parallels the Atlantic coast. It was geologically pierced by the Chagres River at Gatun, but the original gap has been closed by Gatun Locks and Dam. The drainage area of Gatun Lake lies between the two divides.

The existing Panama Canal has been constructed across the narrowest portion of the isthmus generally following the river valleys. The Canal Zone is a strip of land across the Isthmus of Panama extending generally 5 miles on each side of the centerline of the canal. It includes also the areas contained within the 100-foot contour around Gatun Lake and the 260-foot contour around Madden Lake, but excludes the cities of Panama and Colon.

Panama's population centers, Panama City (population 415,000) and Colon (population 85,000), are situated at the ends of the Panama Canal and linked by a railroad and a two-lane highway. Both cities have available the excellent harbor facilities of the Panama Canal Company at Cristobal on the Atlantic side and Balboa Harbor on the Pacific.

The geology of the divide area is complex and characterized by wide variations over short distances between competent rock and materials of very low strength. The terrain on the Pacific side, which includes the Continental Divide, is dominated by conical hills capped by basalt or agglomerate and surrounded and underlain by weak sedimentary and pyroclastic rocks. Materials in the central sector of this area vary from clay shales and soft altered volcanics to relatively strong sandstone basalts. The ridges of the Atlantic coast consist of medium hard sandstones.

The Canal Zone has a typical low-latitude tropical climate. Temperatures are moderately high, averaging about 80 degrees, and rarely exceeding the extremes of 65 and 95 degrees. Relative humidity varies with rainfall. Annual average humidity is about 80 percent and has an average variation from 75 percent in the dry season to 90 percent during the wet season. The Atlantic coast generally experiences higher winds and almost twice the precipitation of the Pacific coast. Annual migration northward in the spring and southward in the fall of the northeast tradewinds and doldrums divides the year into well-defined wet and dry seasons. The dry season is normally from mid-December to mid-April and the wet season the other eight months. October and November have the highest precipitation with rain occurring nearly every day. Seasonal changes may vary as much as one month either way. High-intensity thunderstorms have occurred in every month except February.

The Atlantic and Pacific marine species are closely related, even though few are identical. This condition reflects the fact that these oceans were united until recent geological time, probably three to four million years ago. In general, the Atlantic ecosystems provide more habitat diversity than the Pacific. The differing adaptations and competitive abilities of the biota reflect the differences in environment on either side of the Isthmus.

The Atlantic coastal environment would generally be characterized as mild and constant compared to relatively rigorous and variable features on the Pacific coast. The Pacific undersea slopes are very gently sloping with the 10-fathom isobath varying between 5 to 7 miles offshore. The Atlantic shelf is much steeper with very little area less than 5 fathoms deep.

The Pacific tide is semidiurnal with a maximum range of about 21.1 feet and a mean range of about 12.7 feet. The Atlantic tide is very irregular with a maximum range of about 2 feet and mean range of about 1 foot.

The Atlantic waters exhibit a narrow temperature range for depth and season compared to the slightly cooler Pacific. While the salinities at the Pacific end of Route 15 may approach those of the Caribbean during the dry season, wet season salinities are 4 to 6 percent lower.

Turbidity of Pacific waters tends to be higher than that of the Atlantic. Its nutrient content, benthic biomass and primary productivity are also higher. Food chains are longer in Atlantic ecosystems.

The environmental impact of the proposed action: The proposed plan will produce two prime environmental conversions. One modification involves altering Gatun Lake by pumping in seawater to increase the supply of lockage water. This would render the lake slightly saline and modify its ecology considerably.

Excavations would produce spoil that would have to be placed in adjacent forested areas with a resulting regression in successional status. The rate of biotic development would

be largely determined by the fertility and diversity of the spoil. Igneous material from deep excavations would resist weathering and would be expected to require many ars before reestablishment of mature plant communities. Due to differences in geologic origin of spoil as well as differences in regional and internal drainage, parent material weathering history and successional status, returning plant and animal communities would not be fully identical to the original ones.

Associated with the environmental conversions and the attendant construction activities are additional environmental impacts. Hard rock haul roads and access roads would modify considerable terrain through surfacing and clearing. The increased size and number of ships and the increased salinity of Gatun Lake would allow increased passage of ocean biota through the canal in ballast water, attached to ship hulls or by being locked through.

Any adverse environmental effects which cannot be avoided should the proposal be implemented: Project construction would commit areas of land and water to the environmental conversions previously discussed. Existing flora and habitats would be eliminated through these changes while fauna would be either displaced or eliminated depending on its specific nature.

Hydraulic and dry spoil placed in forested areas would result in destruction of vegetation, burial of detritus layers of the soil and increased sediment load on the region's waterways. This has the effect of regressing successional stages to less diverse, less productive, and thus less stable ecosystems. Unvegetated spoil areas may be considered by some to present a stark contrast (aesthetically) to the lush tropical vegetation of the region.

As increasing quantities of seawater are introduced into Gatun Lake, manyof the plant and animal species would be expected to be eliminated.

Alternatives to the proposed action: The alternatives of location and method of construction have been narrowed down to Routes 10 (Chorrera-Lagarto, Panama), 14 (Panama Sea-Level Conversion) and 25 (Atrato-Truando, Colombia). All routes involve concerns of mixing biota from the two oceans through sea-level construction. Similarly, these alternatives present greater modification of environment through more extensive excavation, spoil disposal and associated stream diversion and flood control structures.

Routes 10 and 14 are comparable in terms of environmental impacts but Route 14 has the disadvantages of interfering with operation in the present canal during construction and eliminating it at the time of its completion. Route 25 is about twice their length, and requires a much greater volume of excavation. Nuclear excavation on this route introduces the concerns of radionuclide transfer and accumulation; genetic alteration of organisms; airblast, ground shock and ejecta damage; and the need for human evacuation and exclusion during excavation and for many months thereafter. All these sea-level routes would accommodate more and larger ships than would an improved lock canal at an increased cost.

Panama's geographical setting is its greatest natural resource, one which can be exploited indefinitely without being expended. The short-term goal of increasing canal capacity will serve a long-range goal of general economic development without significant ecological concern.

The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity: An interoceanic canal already exists in Panama and the development of the region depends primarily upon it. Plans are underway to increase its capacity by pumping seawater into Gatun Lake for increased lockages. Construction of the proposed major modifications to the canal will change only the rate of environmental evolution in the region.

Any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented: The loss of the flora, fauna and habitats of the construction areas and spoil disposal sites would be inherent in the project. More rapid salinization of Gatun Lake would occur with probably deleterious effects on some of the lacustrine ecology.

ROUTE 10 ENVIRONMENTAL IMPLICATIONS STATEMENT

Environmental Statement Pursuant to National Environmental Policy Act of 1969 (P. L. 91-190), Section 102(2)(C) for an interoceanic sea-level canal across Panama.

Project description: Route 10 is the designation given to a proposed sea-level canal to be constructed by conventional techniques along a 53-mile route adjacent to the Canal Zone region of central Panama. This project is designed to improve upon the capability of present Isthmian transit by increasing capacity, updating operations and maintenance characteristics and reducing vulnerability to military attack or sabotage. The need for such a canal is indicated by the limitations of the present facility. In 1970 there were approximately 1,300 ships afloat, under construction or on order which could not pass through the existing locks under any conditions. Approximately 1,700 others could not pass through fully laden. An even more serious limitation is that part of the route is above sea level, and a considerable volume of water is required for the operation of the locks needed to raise and lower the ships during passage. The steady increase in transits, now over 15,000 per year, points out the need for providing more lockage water. Recycling lockage water or pumping seawater must begin within the next several years, undoubtedly before a sea-level canal would be built. As the demand increases, the average transit time will also increase, causing expensive delays. Projections of the postwar demand rate indicate that the number of ships desiring to use the canal would exceed 25,000 per year before the year 2000. A sea-level canal would avoid these limitations and be less expensive to operate and maintain. Blockages by scuttled ships or bomb-induced slides are likely to do no more than slow down passage of combat vessels and medium size merchant ships, and could be removed relatively rapidly.

The Pacific terminus of Route 10 is at the town of Puerto Caimito at the mouth of the Caimito River. The alinement heads northwesterly over the Continental Divide and Chorrera Gap and across arms of Gatun Lake near La Laguna and Escobal. The route terminates at the point where the Lagarto River joins the Caribbean coast.

Most of the excavation along Route 10 would employ open-pit mining techniques, using rail haul for spoil disposal. Truck haul would be used at higher elevations, while

dredges would excavate the approach channels. Barrier dams would maintain Gatun Lake at levels needed for operating the Panama Canal during construction, at the same time permitting excavation at controlled water levels or in the dry. Muck underlying the sites of these dams would be removed by hydraulic dredging, after which spoil from dry excavation would be brought in to construct the embankments.

Diversion of streams on Route 10 would be relatively simple because their drainage basins are small. Most streams would be diverted into the Caribbean Sea; the Caimito River would be the only stream of consequence to discharge into the canal.

Because construction and operation of Route 10 could be supported largely from existing facilities in the Canal Zone and the metropolitan area of Panama, supporting construction requirements would be minimal. Required items would include a transisthmian highway crossing Gatun Lake over the barrier dams; breakwaters on the Caribbean coast; a jetty on the Pacific; and a high-level bridge over the canal.

Reduction of tidal current velocities within the canal would require the use of tidal checks. Under a 2-knot current limitation, expansion beyond the minimum design capacity would require construction of a bypass. The alinement is well suited for a centrally located bypass, excavated through the Gatun Lake reach.

The relatively short length of Route 10 and the high Pacific tides would cause currents greater than 2 knots in an unrestricted channel for short periods of almost every tidal cycle. Unless experience proves that ships can transit safely in currents faster than 2 knots, continuous use of tidal checks would be required. This would set capacity at 38,000 transits per year.

Physical conditions at either end of the alinement are not favorable to shipping. On the Atlantic side, breakwaters would be necessary to overcome the lack of natural protection. The Pacific offers more protection but the approach channel would have to be dredged about 15 miles into the Gulf of Panama. Both approaches would be dredged to 85- by 1,400-foot dimensions.

The design channel would cost about $2.88 billion and take 14 years to construct, including 2 years for preconstruction design. Inclusion of a centrally located bypass section would raise construction costs to about $3.3 billion.

The authority for this study was established by P.L. 88-609 on 22 September 1964, with a basic charge to create a Commission to investigate, study and determine a site for the construction of a sea-level canal connecting the Atlantic and Pacific Oceans. The date of the Commission's report to the President, as amended by P.L. 90-359 on 22 June 1968, is 1 December 1970.

The environmental setting without the project: The alinement of Route 10 lies in the narrowest part of the American Isthmus adjacent to the existing Panama lock canal. It is also the area of lowest topography. The isthmus at this point runs nearly east and west and at its narrowest point is about 40 miles in width (between Limon Bay on the Atlantic and the Gulf of Panama on the Pacific). The trace for the route begins at the village of Lagarto, about 15 miles west of Colon on the Atlantic coast, and extends southeasterly over a range of low hills lying parallel to the coast. This minor divide was geologically pierced by the Chagres River at Gatun, but the original gap has been closed by the Gatun Locks and Dam.

The drainage area of Gatun Lake lies between this range and the Continental Divide that parallels the Pacific coast.

Route 10 crosses arms of Gatun Lake near the towns of Escobal and La Laguna before passing through the divide at Chorrera Gap. It continues south through generally open, rolling terrain crossing the Pan American Highway about 3 miles northeast of La Chorrera. The Pacific terminus of the route is at the town of Puerto Caimito at the mouth of the Caimito River.

The area is relatively undeveloped. The coastal towns are accessible by highways but interior roads are poor to unusable in the rainy season. Gatun Lake in conjunction with the present lock canal provides limited water access to a portion of the route. The area between the Pacific Ocean and Gatun Lake is generally rolling country while the area between Gatun Lake and the Atlantic is quite rugged. The area is sparsely populated and devoted to small-scale farming and livestock production.

The Panama climate is a typical low-latitude tropical climate. Temperatures are moderately high, averaging about 80 degrees, and rarely exceeding the extremes of 65 and 95 degrees. Relative humidity varies with rainfall. Annual average humidity is about 80 percent and has an average variation from 75 percent in the dry season to 90 percent during the wet season. The Atlantic coast generally experiences higher winds and almost twice the precipitation of the Pacific coast. Annual migration northward in the spring and southward in the fall of the northeast tradewinds and doldrums divides the year into well-defined wet and dry seasons. The dry season normally from mid-December to mid-April and the wet season the other eight months. October and November have the highest precipitation with rain occurring nearly every day. Seasonal changes may vary as much as one month either way. High-intensity thunderstorms have occurred in every month except February.

The region of Route 10 is characterized by four main physiographic provinces. The Pacific littoral swamp province extends inland at the lower elevations of the major streams where subsidence of the stream valleys has caused deposition of stream loads forming thick deposits of muck. Igneous complex areas extend from the southern shores of Gatun Lake southward to the swamps of the Pacific shore. The topography is typically steep and rugged at elevations of over 400 feet above sea level. Maximum relief of about 1,200 feet is developed in this rough and irregular terrain. Igneous complex areas are characterized by steep gullies with irregular patterns. The upper portions of hills consist of hard basalts and agglomerates. A stratified rock province extends from the Atlantic littoral swamps and lowlands along the Atlantic coast to the southern shore of Gatun Lake. The province is composed of stratified sediments forming a young coastal plain which gently dips toward the Atlantic Ocean. The Atlantic littoral swamps and lowland comprise portions of Caño Quebrado, the Chagres, Trinidad, and Gatun River Valleys with associated inland and coastal swamp areas. Thick deposits of silt and organic material are intermingled with Pleistocene marine sediments in these valleys.

The Atlantic and Pacific marine species in the vicinity of the route are closely related, even though few are identical. This condition reflects the fact that these oceans were united until recent geological time, probably three to four million years ago. In general, the Atlantic ecosystems provide more habitat diversity than the Pacific. The differing adaptations and competitive abilities of the biota reflect the differences in environment on either side of the Isthmus.

The Atlantic coastal environment would generally be characterized as mild and constant compared to relatively rigorous and variable features of the Pacific coast. The Pacific undersea slopes are very gently sloping with the 10-fathom isobath varying between 5-7 miles offshore. The Atlantic shelf is much steeper with very little area less than 5 fathoms deep.

The Pacific tide is semidiurnal with a maximum range of about 21.1 feet and a mean range of about 12.7 feet. The Atlantic tide is very irregular with a maximum range of about 2 feet and mean range of about 1 foot.

The Atlantic waters exhibit a narrow temperature range for depth and season compared to the slightly cooler Pacific. While the salinities of the Pacific end of Route 10 may approach those of the Caribbean during the dry season, wet season salinities are 4 to 6 percent lower.

Turbidity of Pacific waters tends to be higher than that of the Atlantic. Its nutrient content, benthic biomass and primary productivity are also higher. Food chains are longer in Atlantic ecosystems.

The environmental impact of the proposed action: The proposed plan would produce several prime environmental conversions. Canal construction would convert a 5-mile segment of the Chorrera upland ecosystems, a 5-mile strip of the Colon Province upland ecosystems and segments across about 40 miles of semi-agricultural upland ecosystems to more complex systems containing terrestrial, canal and contact zone components. Similarly, diversion channels for Caño Quebrado and the Trinidad/Ciri Rivers would modify two 5- to 10-mile segments of semi-agricultural ecosystems.

Much of the hydraulic and dry spoil would be placed in adjacent forested areas with a resulting regression in successional status. The rate of biotic development would be largely determined by the fertility and diversity of the spoil. Igneous material from deep excavations would resist weathering and would be expected to require many years before reestablishment of mature plant communities. Due to differences in geologic origin of spoil as well as differences in regional and internal drainage, parent material weathering history and successional status, the returning plant and animal communities would not be fully identical to the original ones.

Barrier dams across segments of Gatun Lake would be required to permit control of water levels within work areas. These structures, measuring 2000 feet wide at their crests, would require prior excavations of about 50 feet of muck to provide a firm base. The lake would be reduced by the area of the structures and subdivided into four separate bodies of water.

Associated with the environmental conversions and the attendant construction activities would be additional environmental impacts.

Hard rock haul roads, access roads and railroad rights-of-way would modify considerable areas of terrain through surfacing and clearing.

Canal construction would create an additional barrier to overland movement and migration of man and wildlife. The salinity of the canal waters coupled with steep banks in areas of hard rock excavation would be expected to create an effective obstacle.

The estuarine ecosystems at the ends of the canal would be considerably altered by the changes in salinity, temperature, turbidity and currents. This modification would act to increase the present diversity of aquatic organisms.

Breakwaters at the Atlantic canal entrance and a jetty at the Pacific entrance would be expected to modify shore currents and littoral drift.

The creation of an unobstructed sea-level canal would greatly amplify the movement between oceans of marine and estuarine life beyond that now passing through the Panama Canal. Such transfer would occur by organisms actively swimming or drifting through the channel, as well as being attached to ship hulls or carried in ballast tanks. There is a reasonable probability that movement of some organisms will constitute new introduction of biota. The likelihood of successful establishment of alien biota in either the ecosystems of the Caribbean Sea or the Pacific Ocean is a subject of debate and is not predictable at the present state of knowledge.

Any adverse environmental effects which cannot be avoided should the proposal be implemented: Project construction would commit considerable areas of land and water to the environmental conversions previously discussed. Existing flora and habitats would be eliminated through these changes while fauna would be either displaced or eliminated depending on its specific nature.

Hydraulic and dry spoil placed in forested areas would result in destruction of vegetation, burial of detritus layers of the soil and increased sediment load on the region's waterways. This would have the effect of regressing successional stages to less diverse, less productive, and thus less stable ecosystems. Unvegetated spoil areas might be considered by some to present a stark contrast (aesthetically) to the lush tropical vegetation of the region.

The migration of biota from one side of the Isthmus to the other would be possible through a sea-level canal; however, the probability of transfer and subsequent effects are not reasonably predictable at present. The prime concern would be for the successful establishment of an undesirable organism with the interrelated possibilities for elimination of critical native biota. Such elimination is visualized through exotic parasite introduction, sterile progeny produced from interbreeding, new predator introduction and merely by the injection of related but more competitive organisms. Since neither the probability of transfer and establishment nor the eventual consequences of "mixing" is assessable for any given class of organisms, it is impossible to categorically state that undesirable introductions can be avoided. There is, however, a justifiable confidence that if pre-construction/pre-operation research indicates a need for a biotic barrier, such a barrier can be implemented utilizing bio-regulators like salinity or temperature.

Alternatives of the proposed action: The alternatives of location and method of construction have been narrowed down to Routes 14 (Panama Sea-Level Conversion) and 25 (Atrato-Truando, Colombia). Route 14 is comparable to Route 10 in terms of environmental impacts but has the disadvantages of interfering with the present canal during construction and eliminating it as a useful facility. Route 25 is about twice the length, and requires a much greater volume of excavation than Route 10. Nuclear excavation on this route introduces the concerns of radionuclide transfer and accumulation; genetic alteration of organisms; airblast, ground shock and ejecta damage; and the need for human evacuation and exclusion during excavation and for many months thereafter.

Another alternative to the proposed action is to recommend against a sea-level canal. This would forego the national defense and shipping benefits of the waterway and permit

both these factors to become major concerns for the present canal in the near future. Overland highways and pipelines would likely be constructed if expanded facilities are not developed. This might have the effect of transferring major environmental concerns from the marine environment to the terrestrial environment. The alternative of modifying the present canal has the obvious disadvantage of impeding traffic during the construction period.

The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity: Considering the interdependence of the components and organisms of an ecosystem, the elimination of a critical species could potentially have far-reaching consequences—to include affecting the long-term productivity of a region. While it is unlikely that elimination of any species would occur over the full extent of its range, the prospect of even restricted elimination is undesirable. It is anticipated that pre-construction research would provide further evaluation of the need for biotic barriers. Investigations to date have not established the need for such barriers.

Areas of infertile spoil would be slow to revegetate and provide balanced land use. While the productivity of these sites would be low, the overall productivity of the region would not be significantly affected.

Any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented: The loss of the flora, fauna and habitats of the construction areas and spoil disposal sites would be inherent in the project.

The concern over the introduction and amplification of undesirable organisms through a sea-level canal is an expression of a never-ending chain of unquantifiable risks. In this case, regardless of the size of the research effort carried out in the immediate future on the ecology of marine organisms, there will remain imposing areas of scientific ignorance. Thus a certain risk of an irretrievable commitment of marine resources would remain with such a project. Continuing research, coupled if necessary with appropriate actions such as the construction of barriers, would be expected to minimize these risks to a level acceptable to those most affected by the consequences.

ROUTE 14 ENVIRONMENTAL IMPLICATIONS STATEMENT

Environmental Statement Pursuant to National Environmental Policy Act of 1969 (P.L. 91-190), Section 102(2)(C) for an interoceanic sea-level canal generally along the route of the Panama Canal.

Project description: Route 14 is the designation given to a proposed sea-level canal to be constructed by conventional techniques along a 53-mile route through the Canal Zone region of central Panama. This project is designed to improve upon the capability of present Isthmian transit by increasing capacity, updating operations and maintenance characteristics and reducing vulnerability to military attack or sabotage. The need for such a canal is indicated by the limitations of the present facility. In 1970 there were approximately 1,300 ships afloat, under construction or on order which could not pass through the existing locks

under any conditions. Approximately 1,700 others could not pass through fully laden. An even more serious limitation is that part of the route is above sea level, and a considerable volume of water is required for the operation of the locks needed to raise and lower the ships during passage. The steady increase in transits, now over 15,000 per year, points out the need for providing more lockage water. Recycling lockage water or pumping seawater must begin within the next several years, undoubtedly before a sea-level canal would be built. As the demand increases, the average transit time will also increase, causing expensive delays. Projections of the postwar demand rate indicate that the number of ships desiring to use the canal would exceed 25,000 per year before the year 2000. A sea-level canal would avoid these limitations and be less expensive to operate and maintain. Blockages by scuttled ships or bomb-induced slides are likely to do no more than slow down passage of combat vessels and medium size merchant ships, and could be removed relatively rapidly.

The alinement of Route 14 is entirely within the Canal Zone and roughly parallels the present lock canal. Construction of a sea-level canal along this route would preclude continued operation of the existing facility.

Route 14 construction would require two principal excavation efforts: dredging across Gatun Lake and cutting through the divide. Across Gatun Lake, deep dredging techniques would be employed, using hydraulic dredges for soft muck, dipper dredges for rock at shallow depths and barge-mounted draglines for rock below elevation +15 feet. Construction plugs would keep the lake at its present level (+85 feet) to sustain operations in the Panama Canal while this work is being accomplished. Scows would move excavated material to underwater spoil areas in the lake. Much of this material would be used as fill in the permanent flood control dams on either side of the alinement. Where practicable, shovels and large dump trucks would be employed to excavate the higher elevations. As the final step of the construction phase, Gatun Lake would be drawn down and the sea-level canal placed in operation. Pools behind the lateral flood control dams would be maintained at an elevation of 55 feet.

Along the Route 14 alinement, about 80 percent of the material could be removed by open-pit mining/rail haul methods; the remainder would be excavated by dipper dredges and hauled in scows to Gatun Lake and the Pacific Ocean.

Flood control and stream diversion involve no serious problems. The two major reservoirs remaining in the Gatun Lake basin would be discharged into the Caribbean, one through the spillway at Gatun, the other through a new outlet east of Cristobal. The Chagres River would be diverted to the Pacific through the existing canal. Smaller streams in either case would be channeled into the canal through inlet structures.

Costs of facilities to support construction and operation of Route 14 are affected by the existing state of development within the Canal Zone. The necessary harbors, communications, and utilities already exist and can be used as they are. Other facilities such as channels and anchorages might have to be modified. In general, however, mobilization for construction on this route would be relatively easy.

The project cost would be approximately $3.04 billion and would require nearly 16 years to complete. Transiting capacity could be increased by extending the two-lane Atlantic approach 9 miles across Gatun Lake at an additional cost of about $430 million.

The authority for this study was established by P.L. 88-609 on 22 September 1964, with a basic charge to create a Commission to investigate, study and determine a site for the

construction of a sea-level canal connecting the Atlantic and Pacific Oceans. The date of the Commission's report to the President, as amended by P.L. 90-359 on 22 June 1968, is 1 December 1970.

The environmental setting without the project: The alinement of Route 14 lies in the narrowest part of the American Isthmus adjacent to the existing Panama lock canal and entirely within the Canal Zone. It is also the area of lowest topography. The isthmus at this point runs nearly east and west and at its narrowest point is about 40 miles in width (between Limon Bay on the Atlantic and the Gulf of Panama on the Pacific). Route 14 lies west of the existing canal on the Pacific side and east of it on the Atlantic, crossing the existing channel near Gamboa at the southerly end of Gatun Lake. The existing canal, railroad and highway provide good access. Towns at either end, Panama City and Balboa on the Pacific and Colon and Cristobal on the Atlantic, are available to support the construction and operation and maintenance efforts. One major concern in the construction and, to a lesser degree, operation and maintenance would be the effect of construction on the stability of the canal slopes through the divide area. This area has a long record of slope failure. Slides during the early life of the Panama Canal closed the canal for extended periods. While recent interference with canal operation has not occurred, continuing efforts to maintain stability are a necessity, even today.

The Canal Zone has a typical low-latitude tropical climate. Temperatures are moderately high, averaging about 80 degrees, and rarely exceeding the extremes of 65 and 95 degrees. Relative humidity varies with rainfall. Annual average humidity is about 80 percent and has an average variation from 75 percent in the dry season to 90 percent during the wet season. The Atlantic coast generally experiences higher winds and almost twice the precipitation of the Pacific coast. Annual migration northward in the spring and southward in the fall of the northeast tradewinds and doldrums divides the year into well-defined wet and dry seasons. The dry season is normally from mid-December to mid-April and the wet season the other eight months. October and November have the highest precipitation with rain occurring nearly every day. Seasonal changes may vary as much as one month either way. High-intensity thunderstorms have occurred in every month except February.

The region of Route 14 is characterized by four main physiographic provinces. The Pacific littoral swamp province extends inland at the lower elevations of the major streams where subsidence of the stream valleys has caused deposition of stream loads forming thick deposits of muck. Igneous complex areas extend from the southern shores of Gatun Lake southward to the swamps of the Pacific shore. The topography is typically steep and rugged at elevations of over 400 feet above sea level. Maximum relief of about 1,200 feet is developed in this rough and irregular terrain. Igneous complex areas are characterized by steep gullies with irregular patterns. The upper portions of hills consist of hard basalts and agglomerates. A stratified rock province extends from the Atlantic littoral swamps and lowlands along the Atlantic coast to the southern shore of Gatun Lake. The province is composed of stratified sediments forming a young coastal plain which gently dips toward the Atlantic Ocean. The Atlantic littoral swamps and lowlands comprise portions of Caño Quebrado and the Chagres, Trinidad, and Gatun River Valleys with associated inland and coastal swamp areas. Thick deposits of silt and organic material are intermingled with Pleistocene marine sediments in these valleys.

The Atlantic and Pacific marine species in the vicinity of the route are closely related, even though few are identical. This condition reflects the fact that these oceans were united until recent geological time, probably three to four million years ago. In general, the Atlantic ecosystems provide more habitat diversity than the Pacific. The differing adaptations and competitive abilities of the biota reflect the differences in environment on either side of the isthmus.

The Atlantic coastal environment would generally be characterized as mild and constant compared to relatively rigorous and variable features of the Pacific coast. The Pacific undersea slopes are very gently sloping with the 10-fathom isobath varying between 5 to 7 miles offshore. The Atlantic shelf is much steeper with very little area less than 5 fathoms deep.

The Pacific tide is semidiurnal with a maximum range of about 21.1 feet and a mean range of about 12.7 feet. The Atlantic tide is very irregular with a maximum range of about [illegible] feet and mean range of about 1 foot.

The Atlantic waters exhibit a narrow temperature range for depth and season compared to the slightly cooler Pacific. While the salinities of the Pacific end of Route 14 may approach those of the Caribbean during the dry season, wet season salinities are 4 to 6 percent lower.

Turbidity of Pacific waters tends to be higher than that of the Atlantic. Its nutrient content, benthic biomass and primary productivity are also higher. Food chains are longer in the Atlantic ecosystems.

The environmental impact of the proposed action: The proposed plan would produce several prime environmental conversions. Canal construction would convert a 40-mile segment of upland ecosystems, about half of which is semi-agricultural, to more complex systems containing terrestrial, canal and contact zone components.

Much of the hydraulic and dry spoil would be placed in adjacent forested areas with a resulting regression in successional status. The rate of biotic development would be largely determined by the fertility and diversity of the spoil. Igneous material from deep excavations would resist weathering and would be expected to require many years before reestablishment of mature plant communities. Due to differences in geologic origin of spoil as well as differences in regional and internal drainage, parent material weathering history and successional status, the returning plant and animal communities would not be fully identical to the original ones.

Flood control dams across Gatun Lake on both sides of the sea-level canal would be constructed to isolate the canal from the lake. These dams would subdivide the lake into four separate bodies of water. Lake water level would be drawn down from elevation 85 feet to elevation 55 feet, thus converting over 100 square miles from a lacustrine ecosystem to wetland and upland tropical ecosystems.

Associated with the environmental conversions and the attendant construction activities would be additional environmental impacts.

Hard rock haul roads, access roads and railway rights-of-way would modify considerable areas of terrain through surfacing and clearing.

Canal construction would create an additional barrier to overland movement and migration of man and wildlife.

The estuarine ecosystems at the ends of the canal would be considerably altered by changes in salinity, temperature, turbidity and currents. This modification would act to increase the present diversity of aquatic organisms.

The lowering of Gatun Lake would reduce the quantity and probably the diversity of the lacustrine biota.

Construction of dams on the Trinidad/Ciri Rivers and Gatun River would slow free-flowing streams and inundate segments of the valleys.

The creation of an unobstructed sea-level canal would greatly amplify the movement between oceans of marine and estuarine life beyond that now passing through the Panama Canal. Such transfer would occur by organisms actively swimming or drifting through the channel, as well as being attached to ship hulls or carried in ballast tanks. There is a reasonable probability that movement of some organisms would constitute new introduction of biota. The likelihood of successful establishment of alien biota in either the ecosystems of the Caribbean Sea or the Pacific Ocean is a subject of debate and is not predictable at the present state of knowledge.

Any adverse environmental effects which cannot be avoided should the proposal be implemented: Project construction would commit considerable areas of land and water to the environmental conversions previously discussed. Existing flora and habitats would be eliminated through these changes while fauna would be either displaced or eliminated depending on its specific nature.

Hydraulic and dry spoil placed in forested areas would result in destruction of vegetation, burial of detritus layers of the soil and increased sediment load on the region's waterways. This would have the effect of regressing successional stages to less diverse, less productive, and thus less stable ecosystems. Unvegetated spoil areas might be considered by some to present a stark contrast aesthetically to the lush tropical vegetation of the region.

The migration of biota from one side of the Isthmus to the other would be possible through a sea-level canal; however, the probability of transfer and subsequent effects are not reasonably predictable at present. The prime concern would be for the successful establishment of an undesirable organism with the interrelated possibilities for elimination of critical native biota. Such elimination is visualized through exotic parasite introduction, sterile progeny produced from interbreeding, new predator introduction and merely by the injection of related but more competitive organisms. Since neither the probability of transfer and establishment nor the eventual consequences of "mixing" is assessable for any given class of organisms, it is impossible to categorically state that undesirable introductions can be avoided. There is however, a justifiable confidence that if pre-construction/pre-operation research indicates a need for a biotic barrier, such a barrier can be implemented utilizing bio-regulators like salinity or temperature.

Alternatives to the proposed action: The alternatives of location and method of construction have been narrowed down to Routes 10 (Chorrera-Lagarto, Panama) and 25 (Atrato-Truando, Colombia). Route 10 is comparable to Route 14 in terms of environmental impacts and has the advantage of not interfering with the operation of the present canal. Route 25 is about twice the length, and requires a much greater volume of excavation than Route 10. Nuclear excavation on this route introduces the concerns of radionuclide transfer

and accumulation; genetic alteration of organisms; airblast, ground shock and ejecta damage; and the need for human evacuation and exclusion during excavation and for many months thereafter.

Another alternative to the proposed action is to recommend against a sea-level canal. This would forego the national defense and shipping benefits of the waterway and permit both these factors to become major concerns for the present canal in the near future. Overland highways and pipelines would likely be constructed if expanded facilities are not developed. This might have the effect of transferring major environmental concerns from the marine environment to the terrestrial environment. The alternative of modifying the present canal has the obvious disadvantage of impeding traffic during the construction period.

The relationships between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity: Considering the interdependence of the components and organisms of an ecosystem, the elimination of a critical species could potentially have far-reaching consequences – to include affecting the long-term productivity of a region. While it is unlikely that elimination of any species would occur over the full extent of its range, the prospect of even restricted elimination is undesirable. It is anticipated that pre-construction research would provide further evaluation of the need for biotic barriers. Investigations to date have not established the need for such barriers.

Areas of infertile spoil would be slow to revegetate and provide balanced land use. While the productivity of these sites would be low, the overall productivity of the region would not be significantly affected.

Any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented: The loss of the flora, fauna and habitats of the construction areas and spoil disposal sites would be inherent in the project.

The concern over the introduction and amplification of undesirable organisms through a sea-level canal is an expression of a never-ending chain of unquantifiable risks. In this case, regardless of the size of the research effort carried out in the immediate future on the ecology of marine organisms, there will remain imposing areas of scientific ignorance. Thus certain risk of an irretrievable commitment of marine resources would remain with such a project. Continuing research, coupled if necessary with appropriate actions such as the construction of barriers, would be expected to minimize these risks to a level acceptable to those most affected by the consequences.

ROUTE 25 ENVIRONMENTAL IMPLICATIONS STATEMENT

Environmental Statement Pursuant to National Environmental Policy Act of 1969 (P.L. 91-190), Section 102(2)(C) for an interoceanic sea-level canal across northwestern Colombia.

Project description: Route 25 is the designation given to a proposed sea-level canal to be constructed by a combination of conventional and nuclear techniques along a 103-mile

route through the Choco Region of northwestern Colombia. This project is designed to improve upon the capability of present Isthmian transit by increasing capacity, updating operations and maintenance characteristics and reducing vulnerability to military attack or sabotage. The need for such a canal is indicated by the limitations of the present facility. In 1970 there were approximately 1,300 ships afloat, under construction or on order which could not pass through the existing locks under any conditions. Approximately 1,700 others could not pass through fully laden. An even more serious limitation is that part of the route is above sea level, and a considerable volume of water is required for the operation of the locks needed to raise and lower the ships during passage. The steady increase in transits, now over 15,000 per year, points out the need for providing more lockage water. Recycling lockage water or pumping seawater must begin within the next several years, undoubtedly before a sea-level canal would be built. As the demand increases, the average transit time will also increase, causing expensive delays. Projections of the postwar demand rate indicate that the number of ships desiring to use the canal would exceed 25,000 per year before the year 2000. A sea-level canal would avoid these limitations and be less expensive to operate and maintain. Blockages by scuttled ships or bomb-induced slides are likely to do no more than slow down passage of combat vessels and medium size merchant ships, and could be removed relatively rapidly.

Route 25 starts in Humboldt Bay on the Pacific coast of Colombia, approximately 200 miles southeast of Panama City. After crossing a narrow coastal strip, the alinement runs eastward for about 10 miles through the Choco Highlands which form the Continental Divide. Turning to the northeast, the trace crosses the upper Truando Valley and the Saltos Highlands and then parallels the Truando River to its confluence with the Atrato River. From there it passes through the Atrato Lowlands for about 50 miles, entering the Caribbean Sea at Candelaria Bay in the Gulf of Uraba at a point 2 miles from deep water.

The plan for building Route 25 assumes the feasibility of nuclear excavation in a 20-mile reach from the Pacific coast through the Continental Divide, the upper Truando Valley, and the Saltos Highlands. The design channel through this region would be over 1,000 feet wide and from 225 to 360 feet deep.

Nuclear excavation would require about 150 individual explosives detonated in 21 separate explosions. Detonations would be scheduled in two passes, the first requiring about 8 months and the second 6 months, with an interval of about 18 months to prepare for the second pass. The largest single detonation would be 13 megatons; the total yield of all explosives in the two passes would be about 120 megatons.

The exclusion area is about 3,100 square miles and has about 10,000 inhabitants. Radiological surveys would be conducted continuously to determine when the area might be reoccupied. Some portions of the area could be re-entered shortly after the last detonation; however, it would probably be more practical to reoccupy the entire exclusion area simultaneously 6 to 12 months after the last detonation. Conventional excavation of a 78-mile reach would begin at an elevation of about 300 feet in the Truando Valley, with shovel excavation and truck haul used at elevations above 75 feet. Over 90 percent of the conventional excavation would be at elevations lower than 75 feet and would be accomplished by hydraulic dredging. The design channel would be 550 feet wide and 75 feet deep at the edges, with a parabolic bottom having a centerline depth of 85 feet. The approach channels would be dredged to 85- by 1400-foot dimensions.

Flood diversion measures would be extensive, since most of the Atrato River would have to be discharged into Colombia Bay through a 1,000- by 50- foot diversion channel east of the canal alinement. Bank revetment would be used to prevent meandering of the realined river and breaching of the separation between the diversion channel and the canal. A smaller but similar floodway west of the alinement would divert runoff from about 2,000 square miles of drainage area into Candelaria Bay. An inlet structure and several diversion channels, excavated with nuclear explosives, would be required to provide flood control and river diversion along the nuclear reach of the canal.

Hydraulic dredges would begin work on the canal within the Atrato Floodplain early in the construction period. During periods of nuclear operations, they would work at the north end of the alinement.

Because of the general lack of development in this region, all facilities required for constructing and operating the canal would have to be provided. These would include a transisthmian highway; harbor facilities; an all-weather airfield; administrative, maintenance, and residential facilities; and bridge or ferry crossings.

Construction of a sea-level canal on this alinement, with a 28-mile bypass channel, would cost approximately $2.1 billion and take about 13 years.

The authority for this study was established by P.L. 88-609 on 22 September 1964, with a basic charge to create a Commission to investigate, study and determine a site for the construction of a sea-level canal connecting the Atlantic and Pacific Oceans. The date of the Commission's report to the President, as amended by P.L. 90-359 on 22 June 1968, is 1 December 1970.

The environmental setting without the project: The American Isthmus in the Atrato-Truando region of the Choco Province in northwestern Colombia is characterized by extremes of high, rugged terrain within sight of low-lying swampland. The distance between the Atlantic and Pacific is approximately 100 miles. The dominating terrain feature is the Atrato River which flows through the northern half of the region from its confluence with the Truando River to the Gulf of Ura[illegible] the Atlantic. The canal alinement would traverse approximately 20 miles of mountainous terrain through which there are passes at elevations between 900 and 1,000 feet. The Curiche River has its headwaters in the Continental Divide highlands and flows westward for about 20 miles before emptying into Humboldt Bay on the Pacific.

The Atrato Valley is a low, broad swamp of post-miocene, unconsolidated alluvial sediments. The Choco Highlands, which form the Continental Divide in this region, are high, narrow ridges of uplifted volcanic rocks.

The area, except for the Atrato River Floodplain, is covered with a dense tropical forest. Trees at higher elevations are short, closely spaced evergreens with a continuous interlaced canopy. Epiphytes and lianas are abundant throughout the tree crowns. Forests of less-dense deciduous trees may be found at upper floodplain elevations. The Atrato floodplain is covered with tall grasses, cane-like palms and shrubs that form almost impenetrable thickets. Rivers are the primary means of natural access into the area.

The Atlantic and Pacific marine species in the vicinity of the route are closely related, even though few are identical. This condition reflects the fact that these oceans were united

until recent geological time, probably three to four million years ago. In general, the Pacific estuarine ecosystem provides more habitat diversity than the Atlantic. The differing adaptations and competitive abilities of the biota reflect the differences in environment on either side of the Isthmus.

The Atlantic coastal environment would generally be characterized as mild and constant compared to relatively rigorous and variable features of the Pacific coast. The ten-fathom contour is two miles offshore on the Atlantic side while deep water is reached in one-half mile at the Pacific coastal terminus. Average rainfall varies from 80 inches at the Gulf of Uraba to 200 inches along the mountainous Pacific coast. The Atlantic tides are irregular, with a mean range of 1.1 feet and a maximum of 2.9 feet. The Pacific tides are regular, having a mean range of 8.4 feet and an estimated maximum range of 14.0 feet.

The Atlantic waters exhibit a narrow temperature range for depth and season compared to the slightly cooler Pacific. The salinity of Atlantic waters is lower and more stable than the Pacific, reflecting higher fresh water inputs from surface runoff waters. Turbidity of Caribbean waters tends to be higher than Pacific while its nutrient content, benthic biomass and primary productivity are generally lower. Food chains are longer in the Atlantic ecosystems.

The environmental impact of the proposed action: The proposed plan would produce several prime environmental conversions. Canal construction would convert a 20-mile stretch of upland ecosystems in the Choco-Saltos Highlands and an 80-mile reach of wetland ecosystems of the Atrato Floodplain to more complex systems containing terrestrial, canal and contact zone components.

Hydraulic spoil (alluvium, overburden, claystone) would be disposed of behind spoil-retaining dikes creating extensive areas of upland ecosystems within the floodplain. Successful invasion by upland vegetation would be relatively rapid.

Nuclear excavation would deposit spoil (primarily igneous materials with small amount of sedimentary rock) in depths up to several hundred feet over an area extending up to 2 miles from the canal. It is predicted that the postexcavation topography will be characterized by a high continuous ridge bounding the canal on either side and standing as much as 500 ft above the present topography. These ridges would have steep slopes into the canal and relatively gentle slopes away from the canal, phasing out and interfingering with the zone of discontinuous ejecta. These ridges would intercept several large streams and numerous lesser drainages. It may be anticipated that numerous artificial lakes would form, varying in size from small to rather large. The calculations indicate that a large part of the Nercua Valley might be inundated. If so, that area (about 16 sq mi) would be lost to potential agricultural development or forest production. The headwaters of several small streams would be buried or diverted by this material.

The effect of the ejecta would be to regress the area's successional status. The rate of biotic development would be largely determined by the fertility and diversity of the spoil. Igneous material from deep excavations would resist weathering and would be expected to require many years before reestablishment of mature plant communities. Due to differences in geologic origin of spoil as well as differences in regional and internal drainage, parent material weathering history and successional status, the returning plant and animal communities would not be fully identical to the original ones.

Associated with the environmental conversions and the attendant construction activities would be additional environmental impacts.

Hard rock haul roads, access roads and railroad rights-of-way would modify considerable areas of terrain through surfacing and clearing.

Canal construction would create an additional barrier to overland movement and migration of man and wildlife. The salinity of the canal waters coupled with steep banks in areas of hard rock excavation would be expected to create an effective obstacle.

The estuarine ecosystems at the ends of the canal would be considerably altered by changes in salinity, temperature, turbidity and currents.

Nuclear excavation on this route introduces the concern of effects of radioactivity, airblast, ground shock and ejecta on the environment; requiring the evacuation of the human population from the area and its exclusion during excavation and for a number of months thereafter.

The Truando, Nercua and Salado Rivers would be diverted to flow directly into the canal. The Truando consequently would become much smaller downstream.

Extensive diversion channels would be excavated on both sides of the canal to accommodate the flows of the Salaqui, Cacarica and Atrato Rivers. Spoil disposal in this area would be behind levees and would raise extensive marsh areas several feet above sea level. The high organic content of this material would aid its rapid revegetation to brush and small trees. The extent of forest development on these areas might be limited by the root-firmness of the fill. The economic value of this land would be enhanced.

The extensive stream diversions, flood control and filled land would alter the entire hydrology and physical characteristics of much of the Atrato Floodplain. The effect on the nearby estuaries would be detrimental. Changes in the frequency, depth and duration of flooding would alter (probably reduce) the nutrient and biotic contribution of the marshlands to the coastal regions. Flora and fauna dependent on these supplies would suffer.

The creation of an unobstructed sea-level canal would greatly amplify the movement between oceans of marine and estuarine life beyond that now passing through the Panama Canal. Such transfer would occur by organisms actively swimming or drifting through the channel, as well as being attached to ship hulls or carried in ballast tanks. There is a reasonable probability that movement of some organisms would constitute new introduction of biota. The likelihood of successful establishment of alien biota in either the ecosystems of the Caribbean Sea or the Pacific Ocean is a subject of debate and is not predictable at the present state of knowledge. Present knowledge does, however, permit the mathematical modeling and estimation of many of the physical processes governing canal transit by an organism.

Any adverse environmental effects which cannot be avoided should the proposal be implemented: Project construction would commit considerable areas of land and water to the environmental conversions previously discussed. Existing flora and habitats would be eliminated through these changes while fauna would be either displaced or eliminated depending on its specific nature.

Hydraulic and dry spoil placed in forested areas would result in destruction of vegetation, burial of detritus layers of the soil and increased sediment load on the region's

waterways. This would have the effect of regressing successional stages to less diverse, less productive, and thus less stable ecosystems. Unvegetated spoil areas might be considered by some to present a stark contrast (aesthetically) to the lush tropical vegetation of the region.

The migration of biota from one side of the Isthmus to the other is possible through a sea-level canal; however, the probability of transfer and subsequent effects are not reasonably predictable at present. The prime concern would be for the successful establishment of an undesirable organism with the interrelated possibilities for elimination of critical native biota. Such elimination is visualized through exotic parasite introduction, sterile progeny produced from interbreeding, new predator introduction and the injection of related but more competitive organisms. Since neither the probability of transfer and establishment nor the eventual consequences of "mixing" is assessable for any given class of organisms, it is impossible to categorically state that undesirable introductions can be avoided. There is, however, a justifiable confidence that if pre-construction/pre-operation research indicates a need for a biotic barrier, such a barrier can be implemented utilizing bio-regulators like salinity or temperature.

Nuclear excavation would require evacuation of all people from an area of about 3,100 square miles with subsequent exclusion until residual radioactivity would be reduced to below acceptable levels. Because of low population density, there would be little damage to buildings or structures from airblast, ground shock or ejecta. Explosions of the planned magnitude have a potential for triggering local earthquakes and earth slides. Such effects are not considered likely. The flora and fauna within the exclusion area, however, would suffer varying damage from effects of ejecta, airblast, ground motion and radioactivity. Radionuclides which may be accumulated in the biota could potentially reach man through native food chains (both terrestrial and aquatic). Tritium, occurring mainly as tritiated water, would likely contaminate local surface and ground water supplies.

Alteration of the Atrato Floodplain by filling and diking would considerably change the inland areas of the entire Colombia bay estuary. Effects such as altered and reduced nutrient input to the estuaries could be detrimental to resident biota.

Alternatives to the proposed action: The alternatives of location and method of construction have been narrowed down to Route 10 (Chorrera-Lagarto, Panama) and Route 14 (Panama Sea-Level Conversion). Both routes have similar environmental impacts, but Route 14 has the disadvantages of interfering with the present canal during construction and eliminating it as a useful facility. Since these routes are excavated conventionally, the environmental impacts related to nuclear excavation would not exist with these plans.

Another alternative to the proposed action is to recommend against a sea-level canal. This would forego the national defense and shipping benefits of the waterway and permit both these factors to become major concerns for the present canal in the near future. Overland highways and pipelines would likely be constructed if expanded facilities are not developed. This might have the effect of transferring major environmental concerns from the marine environment to the terrestrial environment. The alternative of modifying the present canal has the obvious disadvantage of impeding traffic during the construction period.

The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity: Considering the interdependence of the components and organisms of an ecosystem, the elimination of a critical species could potentially have far-reaching consequences – to include affecting the long-term productivity of a region. While it is unlikely that "mixing" of biota would eliminate any species over the full extent of its range, the prospect of even restricted elimination is undesirable. It is anticipated that pre-construction research would provide further evaluation of the need for biotic barriers. Investigations to date have not established the need for such barriers.

The pathways and effects of radionuclides incorporated in an ecosystem are not known with certainty for detonations of the size programmed for canal excavation. Thus many unknowns remain to be cleared before long-term productivity may be assured.

Nuclear excavation introduces a concern for the genetic alteration of organisms through radiation effects. While the possibility of an undesirable mutation exists, it cannot be assessed at the present state of knowledge.

Areas of infertile spoil would be slow to revegetate and provide balanced land use. While the productivity of these sites will be low, the overall productivity of the region would not be significantly affected.

Any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented: The loss of the flora, fauna and habitats of the construction areas and spoil disposal sites would be inherent in the project.

The concern over the introduction and amplification of undesirable organisms through a sea-level canal is an expression of a never-ending chain of unquantifiable risks. In this case, regardless of the size of the research effort carried out in the immediate future on the ecology of marine organisms, there will remain imposing areas of scientific ignorance. Thus certain risk of an irretrievable commitment of marine resources will remain with such a project. Continuing research, coupled if necessary with appropriate actions such as the construction of barriers, would be expected to minimize these risks to a level acceptable to those most affected by the consequences.

Water supplies, food chain organisms and ecosystem components will be subjected to contaminating radiation with a potential for genetic alteration. The state of our knowledge does, however, permit the prediction of allowable dose estimates such that nuclear devices could present a minimal likelihood of increasing the natural mutation rate of organisms.

SUMMARY OF THE BATTELLE MEMORIAL INSTITUTE REPORT ON POSSIBLE EFFECTS OF A SEA-LEVEL CANAL ON THE MARINE ECOLOGY OF THE AMERICAN ISTHMIAN REGION

Construction of a sea-level canal connecting the Atlantic and Pacific Oceans would provide a new pathway for the intermingling of two marine biotas which have been separated by the isthmian land bridge for one to three million years. Some interested observers of sea-level canal feasibility studies have viewed this possibility with alarm, and many suggestions or predictions of deleterious or catastrophic ecological consequences have appeared in both the scientific and the popular literature. Other interested parties, noting that the passage of marine organisms through the present Panama Canal has had no adverse effects on the Pacific or Atlantic Oceans, have argued that construction of a sea-level canal would have virtually no detectable effect on the marine ecology of the Isthmian region. Still others have called attention to the fact that construction of a sea-level canal would constitute a magnificent experiment and provide a great variety of unprecedented opportunities for scientific studies. Our studies have led to the conclusion that present knowledge of the marine ecology of the Isthmian region is not sufficient to permit anyone to predict, with certainty, either the short-term or the long-term ecological consequences of a sea-level canal construction. All we can do at present, on the basis of inadequate evidence, is to offer our educated opinions on the subject and to suggest further studies which would improve the scientific basis for making the desired predictions with less uncertainty. In all probability the basic question, "What would be the ecological consequences of connecting the Atlantic and Pacific Oceans by means of a sea-level canal?", can be resolved only by empirical means. Until the scientific basis for considering this question has been improved by means of pertinent field, laboratory, and theoretical studies, it is likely to remain unresolved and controversial.

This preliminary study was undertaken to: (1) summarize existing information concerning the marine ecology and physical oceanography of the Isthmian region, (2) describe the marine habitats and biotic communities on both sides of the Isthmus, (3) develop preliminary mathematical models to simulate the physical and biological mixing processes that could take place through a sea-level canal, (4) predict the possible economic and ecological consequences of these processes, and (5) recommend further field, laboratory, and modeling studies needed to improve such predictions.

On the basis of the limited ecological information currently available we are unable to predict precisely the specific ecological consequences of marine mixing via a sea-level canal. Preliminary modeling studies indicate that the net flow of water would be from the Pacific to the Atlantic. This would result in minor environmental changes near the ends of the canal and near the shore to the east of the Atlantic terminus. Passive migration of planktonic

organisms would occur almost entirely in the same direction. Active migration of nekton could occur in either direction, but environmental conditions in the canal would favor migration from the Pacific to the Atlantic. We have found no evidence for predicting ecological changes that would be economically deleterious to commercial, sport, or subsistence fisheries. We have found no firm evidence to support the prediction of massive migrations from one ocean to another followed by widespread competition and extinction of thousands of species.

Evidence currently available appears to indicate a variety of barriers to migration of species from one ocean to another and/or the subsequent establishment of successful breeding colonies in the latter. Environmental conditions in the canal would constitute barriers to the migration of both plankton and nekton, and the effectiveness of these barriers could be enhanced by engineering manipulations of freshwater inputs to the canal and other artificial means. The marine habitats and biotic communities at the opposite ends of most proposed sea-level canal routes are strikingly different. Where similar habitats do occur on both sides of the Isthmus, they are already occupied by taxonomically similar or ecologically analogous species. These differences in environmental conditions on the two sides of the Isthmus and the prior occupancy of similar niches by related or analogous species would constitute significant deterrents to the establishment and ecological success of those species which may manage to get through the canal.

It is highly improbable that blue-water species like the sea snake and the crown-of-thorns starfish could get through the canal except under the most unusual circumstances. On the other hand, we can be fairly certain that some Pacific species could pass through the canal and could become locally established in the Pacific waters of the Atlantic. It is also improbable that these species would be able to survive in the Atlantic outside the region of environmental modification due to water flow through the canal. The Pacific species most likely to become established along the Caribbean shore are those of estuarine and other shallow-water habitats, the very habitats that have been least thoroughly studied.

To improve the precision and reliability of these and similar ecological predictions would require additional information and quantitative data which could be provided only by a comprehensive program of field, laboratory, and theoretical (modeling) studies. Extensive taxonomic surveys would be required to improve our knowledge of the biota of the Tropical Western Caribbean and Tropical Eastern Pacific. Except for a few economically important species, ecological life history data are virtually nonexistent. Basic biological studies would be required to obtain such information. The geographical extent and physicochemical characteristics of the marine habitats on the two sides of the isthmus are imperfectly known from a few cursory surveys. The species composition and functional-ecological structure of the biotic communities that characterize these habitats are imperfectly known and inadequately understood. The parameters required to predict the flow of water and plankton through the canal have not been adequately measured. The processes of migration, establishment, and competition have been but little studied and are not well-understood. To remove these deficiencies in our knowledge would require a comprehensive, long-term program of well-coordinated physical oceanography, marine ecology, and basic marine biology studies.

SUMMARY AND RECOMMENDATIONS OF THE COMMITTEE ON ECOLOGICAL RESEARCH FOR THE INTEROCEANIC CANAL, DIVISION OF BIOLOGY AND AGRICULTURE, NATIONAL RESEARCH COUNCIL

1. Summary

Available evidence indicates that the Pacific and Atlantic Oceans were separated when the Central American Atrato Trench closed in the late Pliocene, about five million years ago. The formation of the land bridge resulted in different patterns of selective pressure on the marine biota on either side, leading to unequal rates of speciation and extinction of species in the two oceans. Of unique significance in this regard are the geminate species, because among them can be found examples of every stage in the process of evolutionary divergence. By conservative estimate there are 7,500 Atlantic and 8,500 Pacific species of marine benthic algae and animals now living in Central American waters at depths of 0 to 100 meters. Of these some 700 species are common to both sides, ranging from about two percent of the scleractinian corals to perhaps 20 percent of the polychaetes.

The inherent fragility of natural communities is exemplified by changes in the mammalian faunas of North and South America after they intermingled following the formation of the Isthmian land bridge. Man is now adding a whole new dimension of change over a span of only a few decades. Witness the economic disaster to the fishing industry brought on by the movement of the sea lamprey through man-made canals to the Great Lakes, the introduction into Europe of the Canadian water weed and into Australia and New Zealand of the European rabbit and other exotic mammals and birds. The reversal of such ecological mistakes, even where possible, can be very difficult and costly.

Studies of the Suez Canal indicate that transmigration and colonization of marine biota occur, chiefly from the ecologically more to the ecologically less saturated region; that mobile, active organisms, and fouling organisms, are generally first to make the transit; that large-scale population changes occur; that significant economic impact sometimes results; and that barriers decrease the likelihood of dispersal. There are several possible major consequences of a Panamanian sea-level canal:

- Changes in fisheries resources and the probability that these changes will be uncritically attributed to the canal.
- Introduction of sea snakes and other troublesome marine biota, with consequent danger to recreational users of the marine environment.
- Alteration of marine communities, precluding scientists from gathering information on undisturbed habitats.
- Impact on the resident biota from introduced parasites and pathogens.

– Disruption of the distributions of endemic fresh water organisms before they can be adequately studied.
– Destruction of marine communities, particularly coral reefs, by deposition of spoil and subsequent longshore drift of silt.

Knowledge of the hydrology of a sea-level canal is adequate if not ideal, except for data on disposal of spoil, littoral drift, specifications for tidal locks, and design characteristics of a fresh water barrier. Oceanographic data are scant for inshore regions of Panama and for the offshore Caribbean side; the former are the very waters that will pass with their contained biotas through a sea-level canal. The taxonomy of the marine biota and of natural communities is poorly known for a number of groups; their ecology in shallow waters is virtually unknown. Key communities, particularly the soft bottom shelf, coral reefs and the dominant neritic biota, would need to be monitored over a period of several years. The establishment of biota banks as a permanent record of local biotas and the storage of materials as representative of ecological communities are important corollaries to the overall research. Support for training and research in taxonomy will be essential if adequate surveys and assessments are to be carried out. In any event, manpower and fiscal limitations will necessitate research emphasis on selected groups of organisms; other selected taxa are recommended for studies on ecosystems, dispersal, parasitism, eurytopy, economics and health. Available research resources for Panama, the adjacent coasts of Middle and South America, and the Caribbean Islands are listed along with certain United States institutions where supporting research can be conducted.

The larvae of many tropical invertebrate species seem capable of long-distance travel. Marine organisms transported passively and established away from their place of origin are generally tolerant of environmental fluctuations. Certain mobile, active organisms may easily traverse the canal in either direction. Limited transmigration of pelagic species is likely but there is only a slight chance that meso- and bathpelagic organisms will do so – whether these would constitute propagules cannot be predicted. Early animal invaders might arrive without their characteristic predators and, lacking new predators, become established, forming a new biological balance. Studies on feeding habits of animals would provide information of value in predicting the results of such encounters. Resistance to physiological stress is singularly important in any organism's capacity for dispersal and colonization. Physiological measurements would identify subtle differences between existing populations of the same species and between geminate species and would indicate to what degree the tropical marine biota is stenotopic. Studies of colonization on transplanted substrates and settling plates would offer important information on the potential for dispersal and establishment. Finally, studies on mating behavior and reproductive isolating mechanisms would be essential to an elucidation of evolutionary pathways taken by the biotas under consideration.

Fresh water in the present Panama Canal constitutes a highly selective filter, permitting only the occasional transit of organisms tolerant of a wide range of salinity. It is essential that interoceanic migrations of marine biota through a sea-level canal be similarly prevented, from the outset, by installing a fresh water thermal barrier. Specific salinities, temperatures and lengths of the barrier are suggested; tidal gates would play a critical role.

It is recommended that an entirely new Commission be established, charged with funding and supervising research, administering facilities and ships, soliciting and screening

proposals, and coordinating the activities of various other agencies and institutions. The cost of the ecological research associated with the planning, construction and operating of the sea-level canal is a fully legitimate part of the total cost of this canal and should be borne by the users of the canal. To carry out the Committee's recommendations, support for facilities, staff, operation and maintenance is estimated to be:

Initial Capital Outlay	=	$4,080,000
Annual Budget (first year)	=	$2,668,000
Total Budget (first year)	=	$6,748,000
Annual Budget (second and later years)	=	$2,118,000

The construction of a sea-level canal in Panama is a gigantic experiment with natural ecosystems whose consequences are unforeseeable. A new canal will affect the animal and plant life of the two oceans. What these effects are cannot be determined until and unless the nature of the present differences between the biota and ecosystems of the two oceans is first carefully established through perhaps a decade of intensive research. It is imperative that studies be initiated immediately if a decision on constructing the sea-level canal, in the affirmative, is made.

2. Recommendations*

a. Possible Major Consequences

- Many problems in applied and theoretical biology raised by the impending sea-level canal urgently require solution. The setting is international and calls for involvement by the current CICAR Program (Cooperative Investigations of the Caribbean and Adjacent Regions) of UNESCO, the International Biological Programs, FAO (Food and Agriculture Organization) and other international and national organizations. Because of the need for long-term research on a broad international basis we recommend these problems for inclusion in the International Decade of Ocean Exploration (see Introduction, I-3 and II-3).
- Studies on the nature and extent of natural and fishery-induced population changes are vitally needed in order to distinguish them from any effects of a sea-level canal (see II-2a and IV-5). The following are recommended:
  - Encourage the governments of Panama and other countries with marine resources liable to be affected by the canal – Colombia, Nicaragua, Costa Rica , Honduras, Cuba, Jamaica, Haiti and the Dominican Republic – to develop and perfect their programs for the collection of fishery statistics under FAO auspices.

* References are to the basic study contained in Appendix 16.

– Each of the countries involved should be encouraged through technical assistance to initiate and develop programs of stock assessment in relation to their own fishery resources. The cost of these programs should be shared between the canal and the country concerned.

- Studies on animals and plants of medical importance and those of potential importance to tourism are recommended (see II-3bcd and IV-6).

b. **Hydrology of the Canal**

Although there is considerable information on the hydrology of the sea-level canal, additional data are required on specific questions (see III-2 and IV-2).

- More information is needed to determine (1) how tidal gates would affect currents in the canal and how many hours the gates would have to be closed to achieve zero net flow of seawater, (2) how much fresh water could be available to create a barrier to the dispersal of marine organisms in the canal, (3) the characteristics of temperature-salinity profiles throughout the year (also see section V-4), and (4) specifically where the deposition of spoil would occur, how much material would be spoiled there and what effects the spoilage would have on benthic communities, especially coral reefs.

c. **Oceanography**

- **Nearshore zone processes.** It is essential that basic physical data be collected from the coastal zones of both sides of the isthmus in order to establish present baselines for comparison with future conditions (see III-3 and IV-3). The kinds of data should include:
  – A comprehensive budget of waves, including both swell and wind waves for the offshore areas off each proposed entrance on the Pacific and Caribbean coasts.
  – A detailed study of the types of shore zones and sediments occurring along each coast.
- **Coastal oceanography** (see III-2 and IV-3).
  – **Gulf of Panama inshore survey.** We recommend that an inshore current survey be performed to elucidate the details of the westward coastal flow in the inner Gulf of Panama, to determine the seasonal extent of such flow and the nature of circulation in the Gulf. This coastal water will be the source of supply for Canal water at the most probable environmental monitoring sites.
  – **Gulf of Panama and Caribbean oceanographic surveys.** Oceanographic surveys should be made on both sides of the Canal, with high priority to the Caribbean side, because: (1) general circulation is very much better known on the Pacific side, and (2) it is on the Caribbean side that the effects of the plume from the Canal effluent must be studied. Study of circulation and mixing processes between oceanic and nearshore to coastal waters should be closely coordinated and interrelated, with every effort

being made to have the corresponding oceanic and inshore observations as synchronous as possible.

- Physical oceanographic studies after the installation of the canal can be made at anytime but must be based on pre-canal observations. The rationale for studies of flow patterns, etc. immediately after the canal is opened is therefore to serve the needs of the biological program.

- **Biological oceanography** (see III-3 and IV-3).
  - Large samples of biota, especially planktonic and pelagic organisms, should be taken with comparable, standardized procedures in oceanic, nearshore and canal sampling stations as quantitatively as the contemporary state of the art will permit. These standardized sampling techniques must be continued throughout the period of study in both Pacific and Caribbean areas. Biological data banks should be provided for these samples. A massive collecting effort is essential for detecting propagules.
  - A permanent sampling station should be established near the Caribbean mouth of the canal to monitor on at least a weekly basis the biota present in the effluent water.
  - Comprehensive collection of plankton and other pelagic biota on both sides of the isthmus covering Marsden squares 008, 009, 44 and 45 must be made before the canal is opened. Such a survey should be comprehensive seasonally for at least one year and cover the biota of the upper kilometer of the ocean.
  - Nearshore biological oceanographic studies that are comparable with those on coastal oceanography and current studies must be done in the Gulf of Panama in order to determine the biological quality of the water entering the canal seasonally.
  - Biological oceanographic surveys must be made in the more open ocean, mainly in the Caribbean, to determine, **before** and **after** the canal is open, the gross effects on the oceanic biota in terms of the timing and effect of, e.g., phytoplankton blooms associated with the effluent plume. Area covered should be the bight from Costa Rica to Colombia.
  - A repeat survey of biota should be undertaken over a much wider area of the Caribbean than recommended above to trace the extent of movement of Indo-Pacific forms into the Atlantic.

d. **Marine Biota**

- **Sampling.**
  - We recommend that the marine biota be sampled to a depth of 100 meters from Colombia to Costa Rica (both coasts), with emphasis on Panama and particularly at and near the openings to the sea-level canal. Sampling on the Pacific side must include both upwelling (Gulf of Panama) and, equally important, nonupwelling (Gulf of Chiriqui) regions. Methods of sampling are detailed in Appendix B also see section IV-4a.

- Recommended study areas in Panama are given in section IV-7 for the following habitats: soft bottom shelf, neritic plankton, sandy beach, fouling communities, rocky intertidal, coral reefs and mangrove shores.

- **Taxonomic analysis.**
  - The careful recording of much information on the marine biota must be started as soon as possible. This will include an inventory of characteristic elements of the biota, of the composition of the major marine communities, and of the physiological tolerances, parasites, and pathogens of the dominant components of the biotas (see IV-4b).

  - We recommend that high priority be given to coral reef and subtidal soft bottom communities and the dominant elements of the neritic biota as critical areas of study (see IV-7).
  - It is imperative that additional support be made available for systematic research and for the training of graduate students prior to the opening of the interoceanic canal.
  - Detailed recommendations on taxonomic analysis are given in section IV-4b and include:
    - An intensive study of certain relatively well known groups of organisms, such studies to serve as the base line for analysis of post-constructional changes in the biota.
    - A study of groups of organisms that have particular significance for ecosystem studies.
    - A study of groups containing species with a strong likelihood of dispersing.
    - A study of groups that have species of particular economic or health importance.
  - We emphasize the recommendation that the research areas in the present program be built about specifically solicited, highly qualified personnel.

- **Establishment of biota banks.**
  - It is essential that collections of marine organisms be maintained in permanent repositories in order to compare changes in the marine biota after the canal is opened (see IV-4c). The concept of biota banks includes two necessary functions:
    - Long term storage of materials as a permanent record of a local biota, particularly of taxa that cannot be studied at the present time.
    - Storage of materials as representative of ecological communities.
  - Storage of selected plant and animal material by freezing is recommended.

e. **The Biology of Dispersal and Colonization**

- Selected marine organisms should be reared under laboratory conditions simulating the physical and chemical parameters they would be likely to encounter during their natural dispersal. Emphasis should be placed on eurytopic species, those of commercial importance, those thought to be

dominant species in communities and parasites that may be carried with their hosts (see chapter V and section VI-2).

- An attempt should be made to correlate the breeding habits and dispersal stages of the organisms selected for study with an assessment of larval stages actually predominating in the plankton. There should be included an analysis of the proportion of species with planktotrophic larvae.
- Rearing experiments to determine the length of larval life in the chosen species are recommended. Ancillary information is needed on food requirements.
- Studies on marine larvae must be closely allied with proposed physiological research (see V-4 and VI-3).

f. **Physiological Measurements**

- To provide a basis for prediction of possible colonization after transfer from one ocean to the other and to seek subtle differences between existing populations of the same species and between geminate species, measurements are recommended on the following topics: behavior, protein specificity, reproduction and rate of development, tolerance of environmental extremes, metabolic measurements, and osmotic and ionic regulation (see V-4 and VI-3).
- Particular care must be taken to obtain identical or geminate species from the Bay of Panama and from the Caribbean.
- It is recommended that a comparison be made between animals from corresponding habitats in three areas – regions of upwelling, regions of the Pacific where no upwelling occurs and areas of the Caribbean along northern Panama. Further, it is recommended that to test the postulate that animals in a nonvarying environment have limited capacity for acclimation, studies should be made on similar species from Panama and from a temperate marine environment.
- It is important, if data from the physiological tests are to be used to predict which species may successfully migrate from one ocean to the other, that the preceding studies be initiated immediately.

g. **Food Habits and Dispersal**

- Because of the relationship of food habits and success of dispersal, it is recommended:
  - That studies be carried out on feeding of selected benthic organisms, inshore fishes, and sea snakes.
  - That dominant species be chosen.
  - That certain species of commercial importance and of aesthetic consequence be studied.
  - That species be chosen for research on both larval and adult nutrition (see VI-4).
- Emphasis should be placed on experiments both in the laboratory and under natural conditions to obtain information on selected aspects of feeding behavior (see VI-4).

h. **Role of Passive Transport**

- Plankton carried through the canal by currents should be monitored, particularly to test the effectiveness of the proposed biological barrier (see II-2b, V-2a and VI-5).
- Studies should be carried out on the nature and survival of fouling organisms and of organisms in ship ballast (see II-2b, V-2b and VI-5).

i. **Dispersal and Colonization Experiments**

- The **empty island experiment** is recommended as the best available approach to the assessment of dispersal and colonizing ability (see VI-6). The colonization of transplanted substrates should be studied under natural conditions and experiments with settling plates should be carried out before, during and after construction of the canal.

j. **Parasites and Pathogens**

- An extensive survey of animal and plant parasites and pathogens should be made on both sides of the proposed sea-level canal. The study should include hosts belonging to all the major taxa – vertebrates, invertebrates, and plants (see II-3d, IV-6 and VI-7).
- Emphasis should be placed on selected species that are of potential economic impact and that are deemed to be the most likely candidates to establish themselves after traversing the canal and on those groups that frequently reach epidemic proportions, that is, viruses, bacteria, fungi, protozoans and helminth parasites or pathogens.
- The economically most serious parasites and pathogens of the Atlantic and Pacific should be tested in the laboratory for effects on the similar hosts in the opposite area.
- The degree of specificity of parasites and pathogens is an important subject for research.

k. **Geminate Species**

- Painstaking taxonomic analysis must precede the choice of forms for geminate species studies.
- Studies of pre-mating and post-mating reproductive isolating mechanisms should be made by crossing and observing selected geminate species pairs (see V-5 and VI-8).
- Competition studies should be performed to learn how various closely related animals will interact after a canal is built (should free access be permitted). The ability of various territorial species to exclude resident species can be assessed in a series of controlled behavioral experiments.
- The behavior of geminate predators toward distasteful or dangerous prey species should be studied, and information about the innate and learned aspects of avoidance reactions should be obtained.

l. **Biotic Barriers**

- Considering the grave potential dangers of interoceanic migrations of plants and animals, it is essential that migration be prevented so far as possible by installing the most effective barriers that can be devised. What is required is the establishment of a freshwater-thermal barrier and a closing of tidal gates for such lengths of time as needed to reduce the net flow through the canal to zero (see chapter VII).
- Assumed lethality for 48 hours exposure within a biological barrier:
  - Utilizing salinity alone: 0.5 to 1.5°/oo (parts per thousand); a maximum of 5 percent seawater is recommended.
  - Utilizing temperature alone, 45°C is recommended.
  - Utilizing a combination of dilute seawater (salinity of 3.4°/oo or 10 percent seawater) and high temperature (37-38°C), 48 hours exposure would be effective.
- The size of the barrier needed would depend on the flow of water. Assuming a period of 10 days for water to pass by tidal flow across the isthmus, the above-specified barrier (dilution or heat, or both) should extend for a minimum of 20 percent of the length of the canal, preferably for 40 percent.
- Before the biotic barriers can be designed with confidence, a series of tolerance studies on selected species should be performed. In general, a 48-hour lethal test is sufficient for preliminary screening. However, tolerances should be measured after different salinity and temperature acclimations. The tolerance tests must be implemented at an early stage of planning, as they may influence the specifications for a biotic barrier.
- Provisions must be made to prevent flow through the canal in the event of a mechanical breakdown in one set of tidal gates. The effectiveness of biotic barriers will need to be assessed by continuous monitoring of physical properties of canal waters and its biological components. Prior baseline research on coastal waters is essential in order to permit accurate predictions of the efficiency of the barriers.
- Research on the feasibility of using novel barriers, a bubble curtain or a wall of ultrasonic vibrations, is recommended.

m. **Commission on the Ecology of the Interoceanic Canal**

- We recommend the establishment of a Commission charged with supervising research, administering facilities and ships, soliciting and screening proposals, funding research and facilities, and coordinating the activities of various other agencies and institutions likewise interested in this area (see chapter IX). To do this, a permanent office should be established in the Panamanian area as well as in Washington, D. C. The Commission should have adequate staff support to assist it in carrying out its tasks.
- A distinguished Governing Board should be appointed, charged with supervising the activities of the Commission. Government and nongovernment scientific institutions and agencies should be represented on this Governing Board, as should scientific institutions of the Americas, particularly the countries

bordering the Caribbean. As much of the research will be by contract, review panels of the highest quality are essential.

n. **Needed Facilities, Staff, Operations and Maintenance**

Support of the ecological research associated with the planning, construction and operation of the sea-level canal is to a large extent a legitimate element of the cost of the canal. The Committee recommends that henceforth an item covering these funds be made available from planning, construction and operation resources to the Commission recommended in chapter IX. Until that mechanism can be established it will be necessary to include a line item in the budget of an existing Federal agency to fund the researches that are immediately essential (see Introduction and chapter X).

The budget given below does not include funding for recommendations on fisheries given in section IV-5.

1. Initial Capital Outlay

a.	Administrative Facilities	$ 50,000
b.	Research Laboratories	$1,500,000
c.	Special Equipment for Research	$ 550,000
d.	Equipment for Environmental Surveys	$ 440,000
e.	Ships	$ 940,000
f.	Biota Bank	$ 600,000
	Total 1 =	$4,080,000

2. Annual Budget

a.	Senior Scientists and Staff	$ 800,000
b.	Administrative Staff	$ 100,000
c.	Rental of Administrative Facilities (see 1-a)	$ 3,000
d.	Taxonomic Services	$ 250,000
e.	Operating Costs of Research Facility (exclusive of 2-a)	$ 70,000
f.	Ship Operation, including Personnel	$ 720,000
g.	Service Personnel	$ 40,000
h.	Utilities	$ 20,000
i.	Travel	$ 10,000
j.	Publication Costs	$ 10,000
k.	Library, including Staff	$ 20,000
l.	Governing Board and Review Panels	$ 25,000
m.	Coordinated Programs	$ 500,000
n.	Contingency Funds	$ 100,000
	Total 2 (first year) =	$2,668,000
	GRAND TOTAL 1 and 2 (first year) =	$6,748,000
	TOTAL 2 (second and later years) =	$2,118,000